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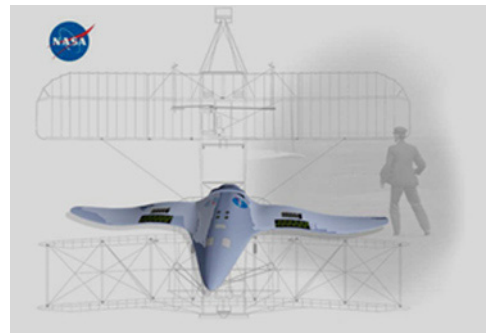
Standard Experiments in Engineering, Materials Science, and Technology

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September 2004

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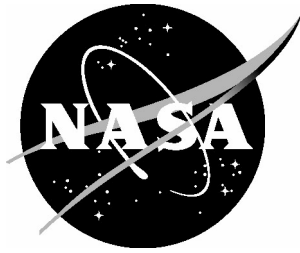
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September 2004

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PREFACE

Organizers of the 18th Annual NEW:Update 2003 were invited to join NASA in its celebration of the Centennial of Controlled, Powered Flight by Orville and Wilbur Wright on December 17, 1903. The Flight 100 theme guided the Organizing Committee to structure activities that provided a historic perspective to take a glimpse back at the remarkable accomplishments of the Wright Brothers as was so ably presented in Bob Ash's, "Uncovering the Secrets of the Wright Brothers". For those of us lucky enough to enjoy warm, torrential rains of Kitty Hawk to witness attempts to recreate the Wright's amazing feat of flight at the December 17, 2003, program, we gained an even greater appreciation of the tenacious voyage the Wright's undertook to finally achieve success in humanities ions of desire to fly with the birds. As these workshop proceedings reveal, a historic view of flight set perspectives for gaining insights into aeronautics and aerospace structures and materials now and into the future as presented by Darrell Tenney and Alan Miller at the Virginia Air and Space Center. Our next venues at NASA Langley Research Center, Thomas Jefferson National Accelerator Facility and the Applied Research Center provided NEW:Update 2003 participants with valuable experiences in structures and materials and related sciences and technologies.

NEW:Update 2003 was built on themes, activities, and presentations based on extensive evaluations from participants of previous workshops as we continued efforts to strengthen materials and technical education. About 200 participants witnessed demonstrations of experiments, discussed issues of materials science and engineering (MS&E) with people from education, industry, government, and technical societies and heard plenary sessions on leading edge developments from experts in their fields. Participants also engaged in valuable mini workshops in state-of-the art laboratories of Langley, Jefferson Lab and the ARC. Faculty, in attendance, represented high schools, community colleges, smaller colleges, and major universities. Undergraduate and graduate students also attended and presented.

With the sponsorship of the newly formed National Institute of Aerospace, this year we inaugurated a special series of events for precollege teachers. Even though hurricane Isabel presented obstacles for full participation, the teachers gained valuable resources and ideas to strengthen their teaching of science and technology as a result of visiting Langley Labs, gaining interactive experiences with problem-solving activities and obtaining a wide range of resources including the unique Langley Structures and Materials kit of specimens that all NEW:Update 2003 participants received. This kit, designed and constructed by NASA Langley technicians as extra duty, was the jewel among many resources educators took away for use as a multiplier of the NEW: Update treasures of technical concepts, pedagogy and laboratory experiments and classroom demonstrations.

Another inaugural event, the brain-child of Zoubeida Ounaies and sponsored by the Biologically Inspired Materials Institute - NASA URETI , was a very successful student poster competition. This event helped gain participation by a significant number of students from regional universities and college students as well as students from across the USA, who also presented papers and demonstrated laboratory experiments, provided valuable input to discussions and helped with our mission of motivating students to strive for excellence.

NEW:Updates continue because of involvement by bright and busy people who squeeze "one more task" into their hectic schedules in order to insure that American education advances thus spurring innovation which helps cement US world leadership in science and technology. Even in a strong economy, gaining funds for educational activities is a challenge. During times of a weak economy, as we experienced during the past few NEW:Updates, the challenges grow. NEW:Updates approach a 3rd decade as a result of vital support from our major sponsors and the many supporters who provide key in-kind assistance and funding. Our local hosts were keys to quality events. Organizers coordinated the many scientists, engineers, professors and other staff, by providing funding, opening their facilities, developing presentations and activities.

NEW:Update 2003 participants saw the demonstration of about fifty experiments and aided in evaluating them. We also heard updating information relating to materials science, engineering and technology presented at mini plenary sessions. The national NEW:Update 2003 Organizing Committee, listed in this conference proceeding, tackled numerous challenges to keep NEW:Update 2003 on track, relevant and full of valuable resources, yet very affordable to participants.

This publication provides experiments and demonstrations that can serve as valuable aids to faculty who are interested in useful activities for their students. The material was the result of years of research aimed at better methods of teaching technical subjects. The experiments, developed by faculty, scientists, and engineers throughout the United States and abroad, add to the collection from past workshops. They include a blend of experiments on new materials and traditional materials.

Experiments underwent an extensive peer review process. After submission of abstracts, selected authors were notified of their acceptance and given the format for submission of experiments. Experiments were reviewed by a panel of specialists through the cooperation of the International Council for Materials Education (ICME). Comments from workshop participants provided additional feedback, which authors used to make final revisions, which were then submitted to the NASA editorial group for this publication.

The ICME encourages authors of experiments to make submissions for use in the *Journal of Materials Education (JME)*. The *JME* offers valuable teaching and curriculum aids including instructional modules on emerging materials technology, experiments, book reviews, and editorials to materials educators. See *JME* subscription information on 1100.

Critiques were made of the workshop to provide continuing improvement of this activity. The evaluations and recommendations made by participants provide valuable feedback for the planning of subsequent NEW:Updates. NEW:Update 2004 will be held at Arizona State University and Phoenix Area industry on October 16 - 20. The growing number of hosts can be seen on our website http://MST-Online.nsu.edu. Click on NEW:Update 2004 for developing information. Join us in beautiful and historic Phoenix in October, 2004, to visit one of the nation's incubators of emerging science and technology and a wonderful environment full of ever changing vistas.

NEW:Update 2003 and the series of workshops that go back to 1986 are, to our knowledge, the only national workshops or gatherings for materials educators that have a focus on the full range of issues

on strategies for better teaching about the full complement of materials, manufacturing and related technologies. Displays by publishers, technical societies, and equipment suppliers add to the workshop's value.

The second edition of *Experiments in Materials Science, Engineering & Technology, (EMSET2) CD-ROM* with over 400 experiments from NEW:Updates, is another example of cooperative efforts generated as a result these annual workshops. The primary contributions came from the many authors of the demonstrations and experiments for NEW:Updates. Funding for the CD came from both private industry and federal agencies. Please see the attached information for obtaining the CD.

Special thanks goes to those on our national Organizing Committee, management team, hosts, sponsors, and especially those of you who developed and shared your ideas for experiments, demonstrations, and innovative approaches to teaching.

The Organizing Committee hopes that the experiments and technical updated material in this publication will assist you in teaching about materials science, engineering and technology. We would like to have your comments on their value and means of improving them. Please send comments to Jim Jacobs, School of Science and Technology, Norfolk State University, 700 Park Avenue, Norfolk, Virginia 23504 or e-mail to dplaclaire@nsu.edu.

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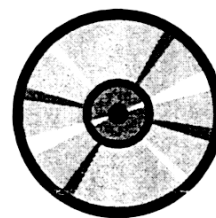
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For more than a decade, the National Educators' Workshops have enabled educators to participate in seminars of peer-reviewed experiments and demonstrations in materials science, engineering and technology. Following each workshop, these papers were published in an annual compendium, with the generous support of NASA.

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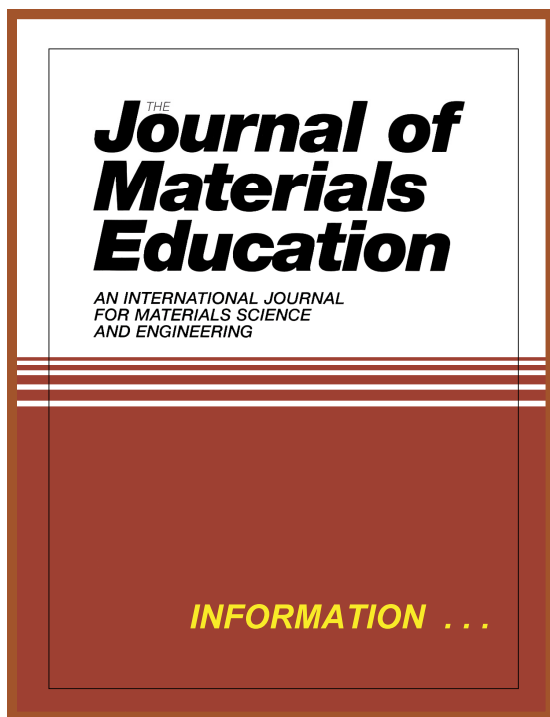
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PROCEEDINGS OF THE SYMPOSIUM ON MATERIALS EDUCATION,
Int. Conf. on Materials for Advanced Technologies, Singapore, July 1-6, 2001
Guest Editors: G.V. Subba Rao, J.E.E. Baglin, B.V.R. Chowdari, Stephan Jaenicke

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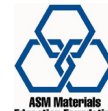
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Problem

- Polymer-matrix composites are ideally suited for space vehicles because of high strength to weight ratios

- The principal component of the low earth orbit (LEO) is atomic oxygen

- Atomic oxygen causes surface erosion to polymeric materials

Objectives and Approaches

To develop durable polymer films for the space environment
Incorporate organometallic additives into high performance polymers (polymer/additive system)

To measure durability of the materials
Expose materials to atomic oxygen in a laboratory-based instrument
Actual space environment exposures on OPM/MIR and MISSE

Advantages of a Polymer/Additive System

- Eliminates the specialized facility and separate processing required for protective coating

- No limitations on the shape and size of film coated

- Additive is uniformly distributed throughout the polymeric material

- No risk of damage to the coating from manufacturing, handling, storage, etc.

- Material is self -healing by forming a new protective surface if damaged

- Leads to enhanced durability

Molecular Structures

POLYETHERIMIDE (ULTEM)
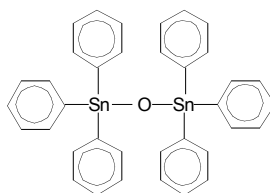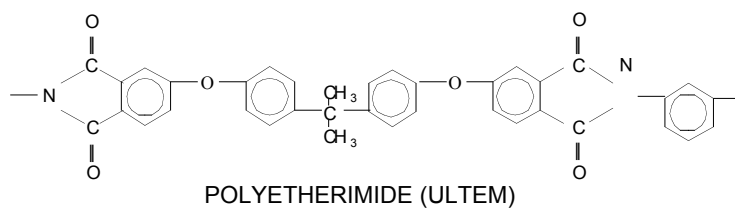
BIS(TRIPHENYLTIN) OXIDE (BTO)

ODA

PMDA

H_2N —⟨ ⟩— O —⟨ ⟩— NH_2 +

N₂
DMAc
Room Temp

Polyamic Acid

Thermal
Imidization   -2H₂O

PMDA-ODA Polyimide (Kapton)

[CH₃COCH=C(O-)CH₃]₃Al

$$[CH_3COCH=C(O-)CH_3]_3Al$$
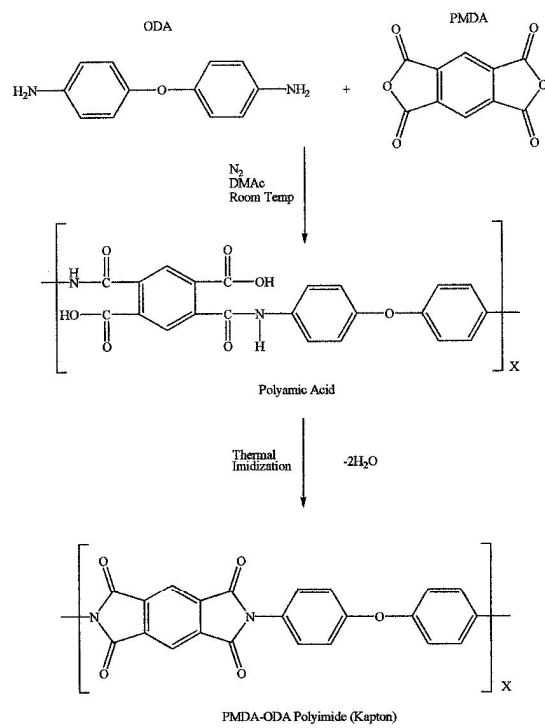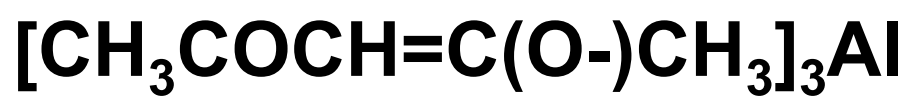
Aluminum Acetylacetonate (Alacac)
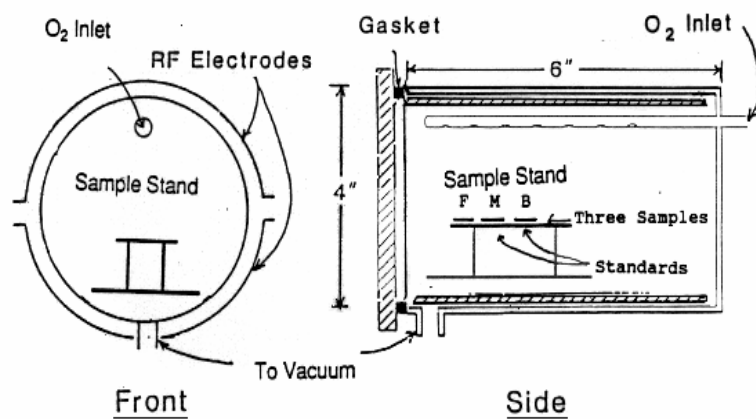
Reaction Chamber for Atomic Oxygen
Experiments

X-ray Photoelectron Spectroscopy of Kapton with 10% Alacac
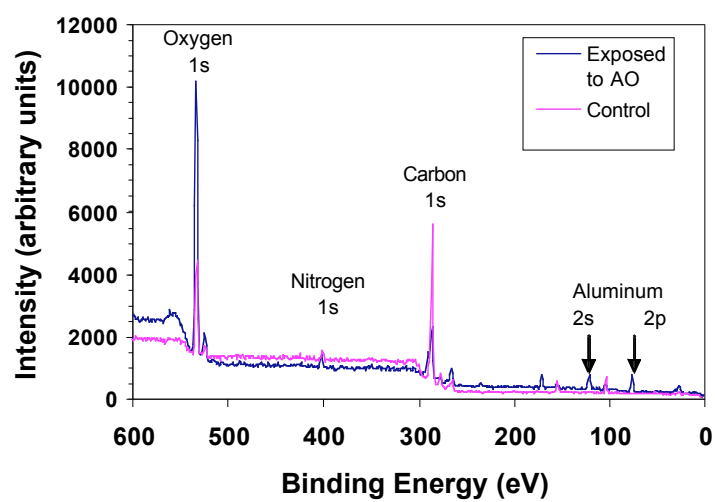
	Atom Percent		
	C	**O**	**Al**
Control	71.3	19.0	0.2
Exposed to AO	34.3	45.9	8.9

Table showing the changes in surface composition of Kapton/10% Alacac after exposure to AO.

The Optical Properties Monitor (OPM) Experiment

As part of the Optical Properties Monitor experiment, three   Ultem /BTO samples were exposed in space from April 29, 1997 to January 8,1998 on the MIR Space Station.
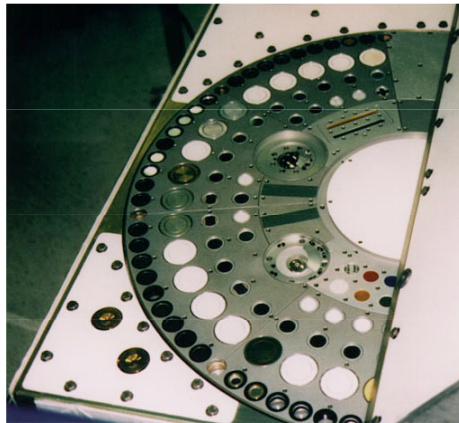
Optical Properties Monitor (OPM)

Russian MIR

Results of OPM/MIR Flight Experiment

Material	Mass Loss Data		Atom % from XPS: Postflight Pre-flight		
	Mass Loss (mg)	% Mass Loss	C	O	Sn
Pure Ultem	0.33	1.67	52.5 81.0	33.0 14.2	-
Ultem/10% BTO	0.32	1.42	24.7 79.7	50.1 15.2	8.7 0.6
Ultem/20% BTO	0.19	1.04	24.6 77.7	50.2 17.2	10.1 0.8

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Materials

International

Space

Station
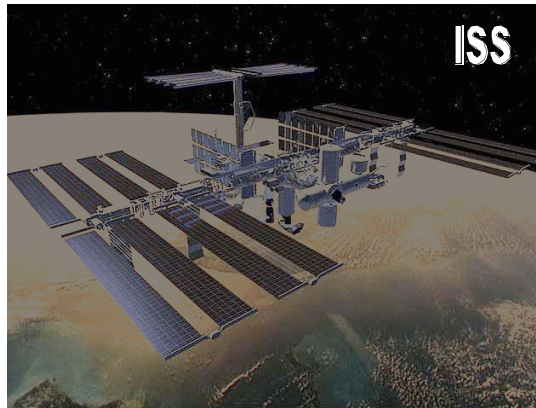
Experiment

The <u>M</u>aterials on the <u>I</u>nternational <u>S</u>pace <u>S</u>tation <u>E</u>xperiment (MISSE)
is designed to expose materials to the space environment either with
or without exposure to AO. Two of our samples are exposed in the
ram direction (AO and UV) and three samples are exposed
in the wake direction (UV only).

MISSE Specimens

2-K1
Kapton

2-K2
Kapton with 10% by weight
aluminum acetylacetonate(Alacac)

AO plus Solar exposure
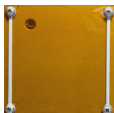
1-J11
Kapton

1-J12
Kapton with 10%
Alacac

1-J13
Kapton with 15%
Alacac

Solar exposure only (no AO)

PEC 2 - TRAY 2
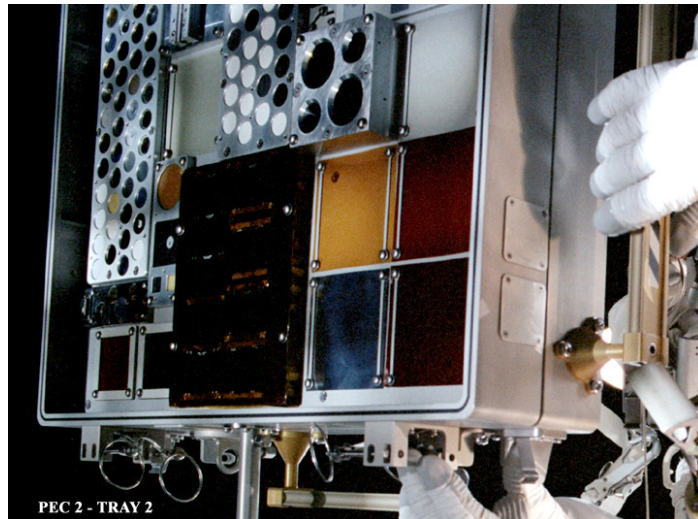
Deploying samples in the wake direction (UV only) on 08/10/01

PEC 2 - TRAY 1
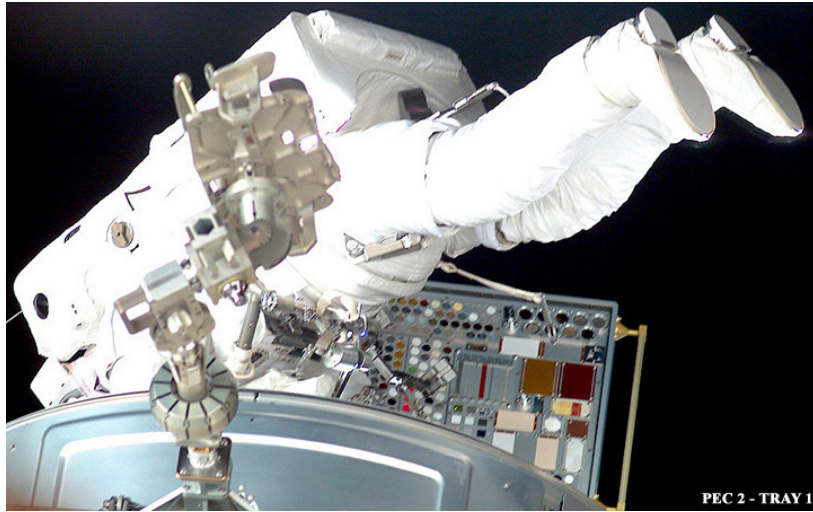
**Deploying samples in the ram
direction (AO and UV) on 08/10/01**

**Ram direction of MISSE
photographed on 12/05/01
showing samples
still intact**

**Ram direction of MISSE photographed on 04/08/02
showing the pure Kapton film gone**
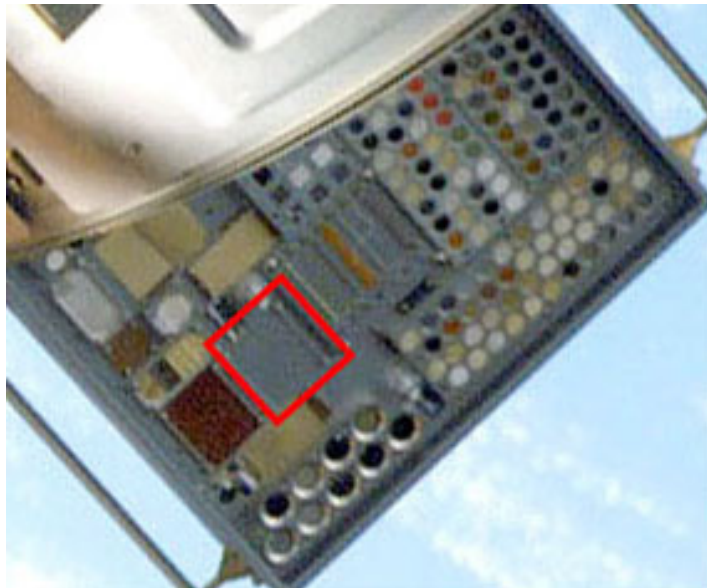
**MISSE ram direction photographed in May, 2002
showing the pure Kapton film missing but the
Kapton/10%Alacac intact**
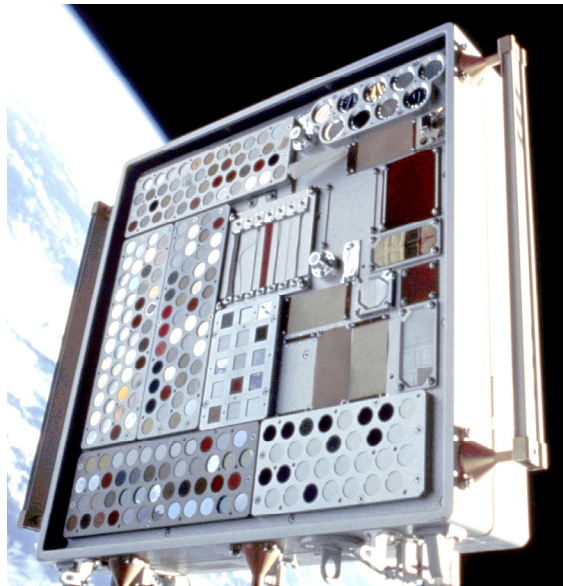
MISSE wake direction photographed in May, 2002, showing samples still intact
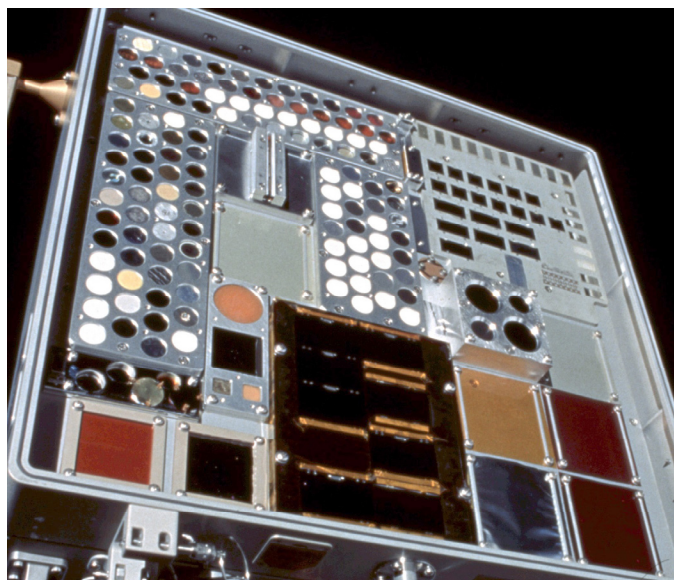
Conclusions

Polymer films with an organometallic additive showed greater resistance to atomic oxygen than the pure polymer in laboratory experiments and in the OPM/MIR experiment.

In MISSE, the film with the organometallic additive was still intact after the pure film had completely eroded.

BUBBLE TROUBLE
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Bubble Trouble

National Educators' Workshop
October 19 – 22, 2003

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Key Words: Density, Gas Density, Vapor Density, Sublimation, Soap Bubble, Helium, Dry Ice, Carbon Dioxide, Air

Prerequisite Knowledge: Basic understanding of physical properties of gases and states of matter.

Objective: To demonstrate the concept of gas/vapor density, using bubbles as containers, and then relating the observations back to real world applications.

Equipment and Materials:
1. Six foot length of 3/4" PVC pipe (can buy PVC components at local hardware store such as Lowe's or Home Depot)
2. Two 90° PVC elbow joints
3. One PVC straight joint
4. Clear 2-L plastic soda bottle
5. Paper towel
6. Rubber band
7. Tall ring stand with clamp
8. Measuring cup or shallow dish
9. Ivory Liquid dish detergent
10. Rubber tubing
11. Helium gas (can buy at Walmart in party section)
12. Dry ice - for carbon dioxide (CO2) gas generation (can be obtained from fire extinguisher companies, fish markets, and some grocery stores such as Kroger that sell dry ice in blocks)
13. Hair dryer

Introduction:

Density is the mass per unit volume of any substance, including liquids. The density of a material helps to distinguish it from other materials. Since mass is usually expressed in grams and volume in cubic centimeters, density is expressed in grams/cubic centimeter. For example, you have two balls, a basketball and a bowling ball, and both are the same size. Since the bowling ball is heavier than the basketball, you know that it has to be more dense, since they both take up the same amount of space overall. The density of a liquid determines whether the liquid will sink or float on water. A good example of this is Italian salad dressing in which the salad oil is floating on top of the vinegar. The density of vinegar is similar to water. The density of the oil is lighter than water therefore the oil floats on top of the vinegar.

The density of a gas is the mass per a unit volume of a given gas relative to that of air. It is usually expressed as grams per liter (g/L) at a specific temperature. [Note that gas density is slightly more complex than discussing solid/liquid density since gas volume is very responsive to

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temperature and pressure.] Vapor density is slightly different from gas density in that it simply indicates how many times the vapor of a substance is heavier than air. It does not have a unit and it is written as a number followed by "air = 1" in parentheses. Vapor density is calculated by dividing the molar mass of a substance with that of air where the molar mass of air is equal to 29 g/mol. It is often necessary to know whether a gas and/or the vapors of a hazardous substance are heavier than air. Heavier gases/vapors can accumulate in low spots whereas lighter gases/vapors will rise and disperse. Heavier gases/vapors present a particular hazard because of the way in which they accumulate. For example, vapors of a flammable liquid that are heavier than air can present a "flashback" fire hazard. They travel along low spots away from the flammable liquid source. If they encounter an ignition source at some distance away, the vapor will ignite and follow its path back to the flammable liquid source, similar to a fuse on a stick of dynamite. Toxic gases can accumulate and poison workers; non toxic gases may displace air and cause suffocation.

Knowing the density of a substance can also lead to useful applications. For example, carbon dioxide, which is heavier than air, is used to extinguish fires. Carbon dioxide smothers a fire by forming a blanket of gas on top of the fire and pushing out the air. Without air, the fire cannot burn. Density measurements are an important analytical technique in a variety of applications as well. The condition of an automobile storage battery can be judged by measuring the density of the electrolyte, which is a sulfuric acid solution. As the battery discharges the acid combines with the lead in the battery plates to form insoluble lead sulfate, decreasing the density of the solution. The density is measured with an instrument, a hydrometer, by observing the level at which a calibrated body floats in a sample of the solution. Medicine has many uses for density too. Some examples include tests on body fluids such as blood and urine. An unusually low density in blood may indicate anemia. Certain diseases can increase the salt level in urine and thus the urine density.

This experiment focuses on scientific observation of gas/vapor density behaviors. We do this by filling a container with a certain amount of gas and observing if rises or falls. In this demonstration, a soap bubble serves as the "container." Some gases, such as helium and hydrogen, have a density that is less than the density of air, so soap bubbles filled with lighter gases will rise. The speed with which they rise is an indication of just how much lighter the gas of interest is than air. You will note that the helium filled bubbles will rise very quickly. Other gases, such as carbon dioxide or nitrogen, have a density that is heavier than air, so soap bubbles filled with these gases will fall to the ground. Theoretically, bubbles filled with air should remain suspended in air indefinitely since their densities are the same. But air-filled soap bubbles will eventually fall to the ground due to the added weight of their containers, the soap bubbles.

Experimental Procedure:

1. Mix 10 ml of Ivory Liquid with 200 ml of water in a measuring cup. Let stand.
2. Cut a 3 cm hole in the side of the 2-Liter bottle near the top.
3. Cut the 6 foot PVC pipe into three pieces as follows: 5 ft, 10 inches, and 2 inches. Use the three pieces of pipe and two elbow joints to construct a large faucet head as shown in the Figure 1.

Figure 1
Experimental Set-up

10 in

2 in

Paper towel

5 ft

2 Liter soda bottle filled
with water
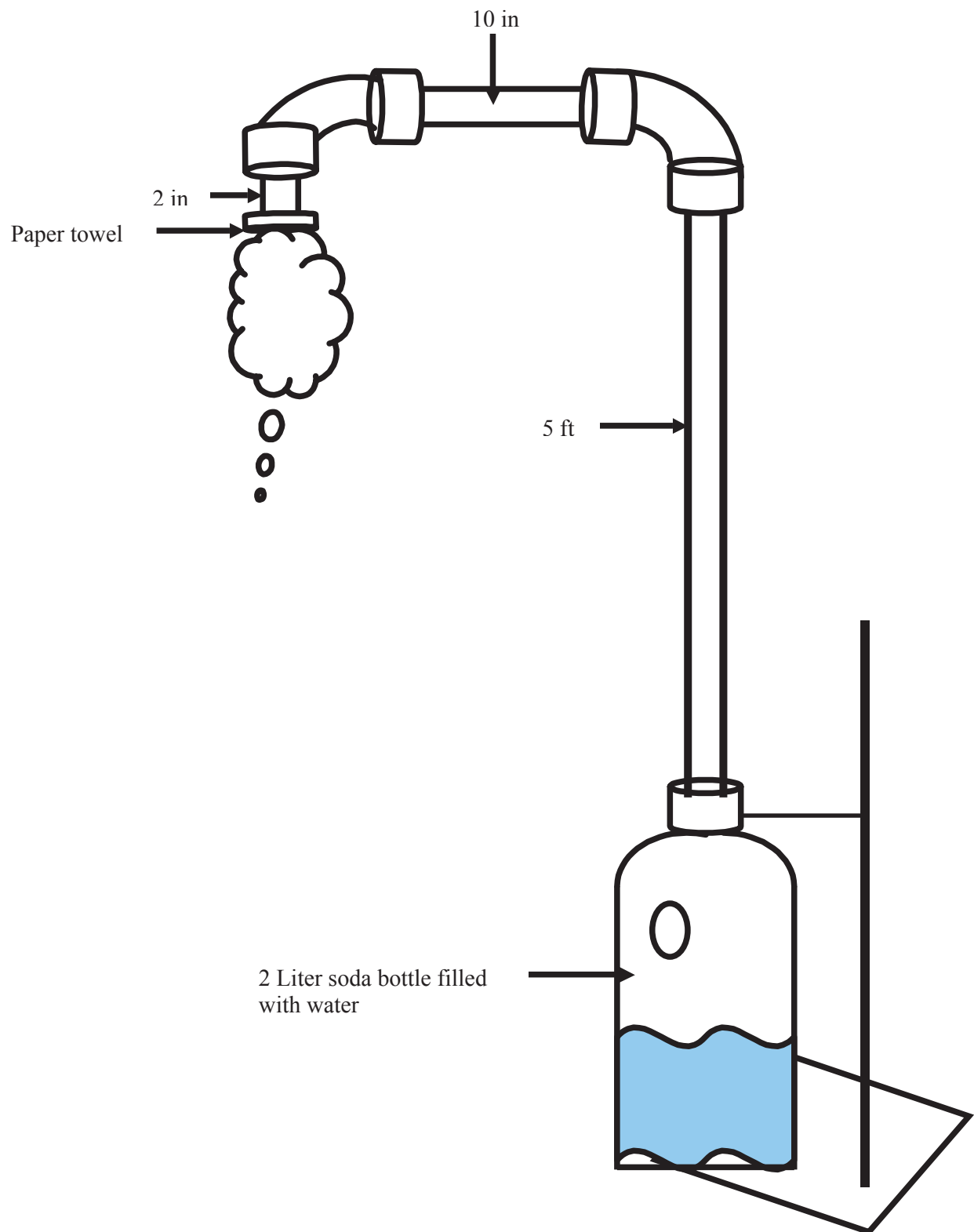
4. Roll up the paper towel and moisten it with water. Wrap the moistened paper towel around the mouth of the faucet and secure it with the rubber band.
5. Secure the 5 foot piece of pipe to the ring stand with a clamp. Be sure to position the pipe opening over the mouth of the soda bottle.
6. Seal all connections with electrical or duct tape. This is important to ensure your gas does not escape and is directed out of the faucet opening to form and fill the bubble.
7. Hold the cup of soapy mixture up to the mouth of the faucet to wet the paper towel and create a soapy film across the pipe opening. This works best if you hold the cup level with the faucet opening.
8. Pump the helium gas into the bottle through the side opening via the rubber tubing. To prevent gas from escaping out of the bottle opening, cover the hole with tape.
9. For helium bubbles, rotate the faucet opening 45° (Figures 2 & 3). Otherwise, the bubble will form into itself coming in contact with the faucet and popping the bubble before it is completely formed.
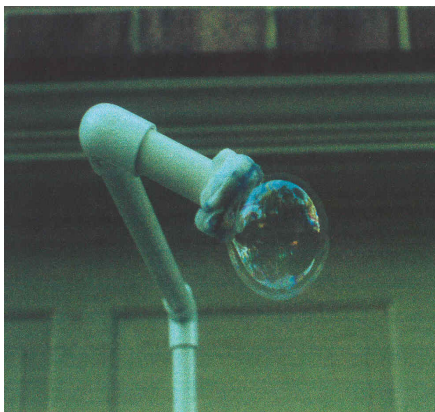
Figure 2. Faucet at 45°   Figure 3. Helium Bubble
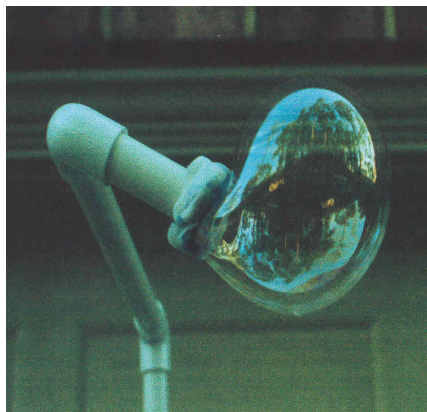
10. To generate carbon dioxide gas, place small chunks of your dry ice inside the bottle. When the dry ice chunk hit the water, they will rapidly sublimate and produce carbon dioxide gas. If you have trouble filling your bubbles with the carbon dioxide gas, check the seals on your apparatus as you may have a leak that can significantly affect your bubble formation.

Comments:

Helium filled bubbles really move. When they break, a little white film falls to the ground. This is the soap film that's leftover after the bubble pops. Heavier gases cause the bubble shape to look like a teardrop as it forms (Figure 4). Also, colder gases, such as the carbon dioxide released from dry ice, make the bubble look cloudy because of the water mist that condenses from the air when the super cold gas comes in contact with the water and begins to sublimate. Note that the carbon dioxide bubbles appear to be filling with smoke. Ask your students what this is. Students find it fascinating to watch a CO2 filled bubble break because it looks like a smoke ring when the water mist is released (Photo 4). Students also like to try and catch the bubbles as they fall. They will feel cool as they break in their hands.
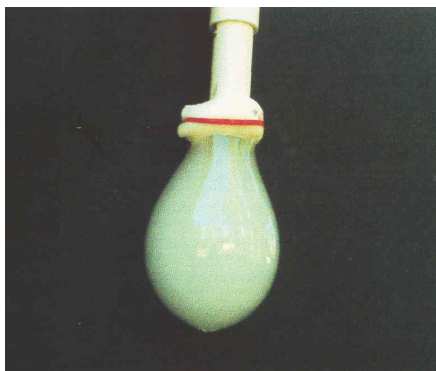
Figure 4. CO2 Bubble
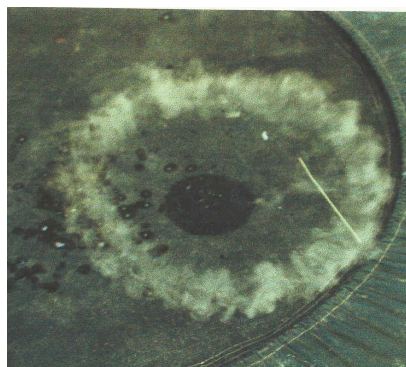
Figure 5. CO2 Bubble burst
Note the ring of water mist.

You can have the students guess whether the bubble will rise or fall based on information you give them about the gases. They can also observe the appearance of the bubble. Air filled bubbles tend to stay somewhat suspended in the air. They eventually fall to the ground and break. Given that they are air bubbles in air, one would think they would stay suspended indefinitely. Ask the students why they fall. They should be able to tell you it is because of the weight of the soap bubble that they follow a slow downward path!

References:

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2. Patnaik, P. 1999. A Comprehensive Guide to the Hazardous Properties of Chemical Substances. 2nd ed. New York, NY: John Wiley & Sons, Inc.
3. Plog, B.A.; Benjamin, G. S.; and Kerwin, M. A.; Fundamentals of Industrial Hygiene.3rd ed. Chicago, IL: National Safety Council.
4. Cox, D. B. and Borgias, A. P.; 2000. Hazardous Materials Management Desk Reference. New York, NY: McGraw-Hill Companies, Inc.

Bibliography:

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LOCATING BREAKPOINTS IN A DISCONTINUOUS POLYNOMIAL FUNCTION
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Locating Breakpoints in a Discontinuous Polynomial Function

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Key Words:

plastic deformation, critical strains, tensile stress-strain behavior, numerical analysis data, MATLAB software

Prerequisite Knowledge:

Engineering Mechanics, Numerical Analysis, Physical Metallurgy

Objectives:

We endeavored to find optimum techniques to establish breakpoints in plastic residual strain data that fit a piecewise discontinuous polynomial function. These breakpoints are an unexpected phenomenon in strain versus relative position data obtained from tensile bar specimens deformed to failure. These breakpoints appear to be discontinuous second order transitions between regions of differing stress-strain behaviors and are called critical strains. The five methods used are visual, local slope analysis and three methods using numerical analysis techniques augmented by programming of MATLAB.

Equipment and Materials:

The specimens were tensile specimens of various alloys that had been fractured in student laboratory classes. The diameter and position data used for determining the plastic strain profiles were obtained using two Keyance Laser Micrometers and an X-Y stage. The analytical techniques applied to the data employed Excel spreadsheets and MATLAB software.

Introduction:

The analytical techniques used to find breakpoints in a piecewise discontinuous polynomial function were first intended to analyze residual plastic strain data obtained from tensile bars pulled to failure. The data was taken using laser micrometers to measure diameter

and relative axial position and later converted to strain versus relative position using the constant volume relationship for crystal plasticity. The strain versus relative position graph appears to be a piecewise discontinuous polynomial function.

We are interested in finding the breakpoints in the strain versus position data because these breakpoints appear to be critical strains. James Bell, professor at Johns Hopkins University first identified critical strains. He began his studies in dynamic crystal plasticity during the early 1950's when he examined strain behavior of symmetrical rod impact specimens. Bell identified that the plastic strain region of these specimens is not continuous and he defined the breakpoints in plastic behavior as critical strains. Bell also stated that the critical strains are "independent of stress, particle velocity, ambient temperature, strain rate, specific crystal structure, purity and type of metal" and are found in all polycrystalline materials (Bell). Bell first found these critical strains occurred at strains equal to $2/3^{n/2}$, where n is equal to 0,2,4,6,8,10, 13, and 18 (Bell).

Subsequent research by R. B. Pond, Jr. concluded that critical strains occurred in dynamically loaded, symmetric impact bars at strains equal to $2/3^{n/4}$, for which n equaled many integers. Our recent research with tensile bars suggests that critical strains occur at values equal to $2/3^{n/8}$ for all integer values n in ordinary tensile specimens.

Our studies were conducted within the Loyola College Hauber Fellowship Program, an undergraduate research program that funds Loyola College summer research students. The U.S. Army at Aberdeen Proving Ground in turn supported our Hauber program.

Procedure:

Five methods were used to find the breakpoints in the plastic strain behavior. Those methods are:

1. A method using a visual interpretation of the data to determine changes in strain behavior.

2. A local slope method involving analyzing the slope between each data point.

3. A MATLAB routine with a moving window in which a predetermined number of data points inside the window would be fitted and the next data point would be calculated using the fit. This calculated value is compared to the actual data point value as the window moves in one data point increments through the data set. The transition points were determined from local maximums in the difference between calculated and actual values.

4. A MATLAB routine with a moving window that fits a set amount of data points and records the coefficients of the fit. The window then moves to the next data point and repeats the fit. The fits are then analyzed for strain locations of maximum changes in the coefficients.

5. A MATLAB routine that begins at one of the original Bell critical strains and creates a window of data. The data in the window is fit to a cubic function. The difference between the functional fit and a cubic spline fit between each data point is calculated. The window continues to increase in size until a specific, large difference is found between the cubic spline and the analytical function and the strain location of the deviation is recorded. The window then is moved to the recorded strain and the process is repeated.

All five methods were used to analyze a brass tensile bar that was strained to failure. To perform method number one many graphs were obtained with 20 to 30 data points in each graph (Figure 1) and ranged the entire data set. Using visual interpretation, changes in strain behavior were noted as critical strains. Method number two involved graphing local slope vs. position for a small portion of the data set (Figure 2). Visual interpretation was used to find local maximums and minimums, which again were noted as transition strains. To perform method number three, the window size was set to five data points and a MATLAB routine was used to find local maximums. Method number four used a window size of four data points and critical strains were found by finding regions of constant coefficients.

Due to the sensitivity of method number five to the number of data points between each critical strain, the data set was obtained with six to eight data points between the hypothesized critical strains using the $2/3^{n/8}$ formula. The plastic strain for the data set ranged from 82% to 7%.

Comments:

After performing each method to analyze the data set, graphs were formed to compare critical strains of each method (Figures 3-5). These graphs show the critical strains found using each method in addition to the hypothesized critical strains using the $2/3^{n/8}$ equation. Each method was then analyzed for how many critical strains were found, the percent of found critical strains that were within 1% of a nominal critical strain and the percent of hypothesized critical strains that were reported. Method one returned a total of 39 found critical strains. Of these found critical strains, 49% were within 1% of a nominal critical strain. Fifty-eight percent (58%) of the hypothesized critical strains within the data set range were found using method one. Method two returned 53 found critical strains, 53% of which were within 1% of hypothesized critical strains. The critical strains determined using method two corresponded to 64% of the hypothesized critical strains. Method three resulted in 59 found critical strains, 39% of which were within 1% of a hypothesized critical strain. Method four returned 36 found critical strains, 56% of which were within 1% of a hypothesized critical strain. Method five resulted in 70 found critical strains and 31% of those were within 1% of a hypothesized critical strain. Methods three, four and five had found strains that corresponded to 50%, 38% and 49% of the hypothesized critical strains inside the data set, respectively.

When comparing the nominal critical strains to the measured critical strains for each method, it appears methods one and two most provide the closest correlation of breakpoints with nominal critical strains. Method one possesses the problem of subjectivity and therefore has no mathematical basis. Method two returned many of the hypothesized critical strains and did not

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return many non-hypothesized critical strains. Additionally an analytical technique could have been used to determine the local maximums and minimums for this method. We note that not all local maximums and minimums using this method coincided with the nominal critical strains.

Method three returned average results when compared to all five methods, but there is a limitation that arises when this routine is applied with only a few points between critical strains. In this case the fit may not represent the entire strain behavior and poor results will be reported. Method four had the highest percentage of determined transition strains being within 1% of a hypothesized critical strain of all the MATLAB routines, and resulted in 38% of the hypothesized critical strains found. This means method four is accurate, but does not identify all of the transition strains. A more advanced routine to analyze the graph of coefficients may improve method four's results.

Method five resulted in many non-hypothesized critical strains, but while only 49% of the hypothesized critical strains were found, method five was only one data point off for an additional 35% of the hypothesized critical strains, meaning the routine was within one data point of returning 84% of the hypothesized critical strains. This shows that the routine works, but is not accurate enough. Figures 3-5 show that all methods provide closest correlations between measured transitions and nominal critical strains at strains below 40%.

This research is continuing to further refine the description and possibly the understanding of critical strains in crystal plasticity.

References:

Bell, James. The Physics of Large Deformation of Crystalline Solids.Springer-Verlag New York Inc. New York. 1968.

Figures:

Sample of Strain % vs. Position
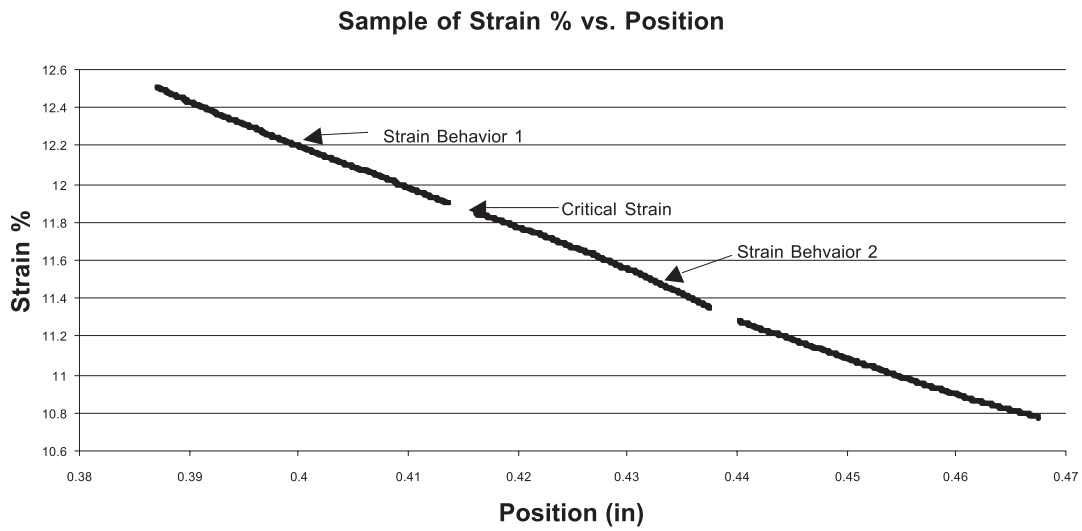
Figure 1: Small section of data set showing strain percent vs. position. This section is used to help find changes in strain behavior using method 1.

Local Slopes of Strain vs. Position Graph
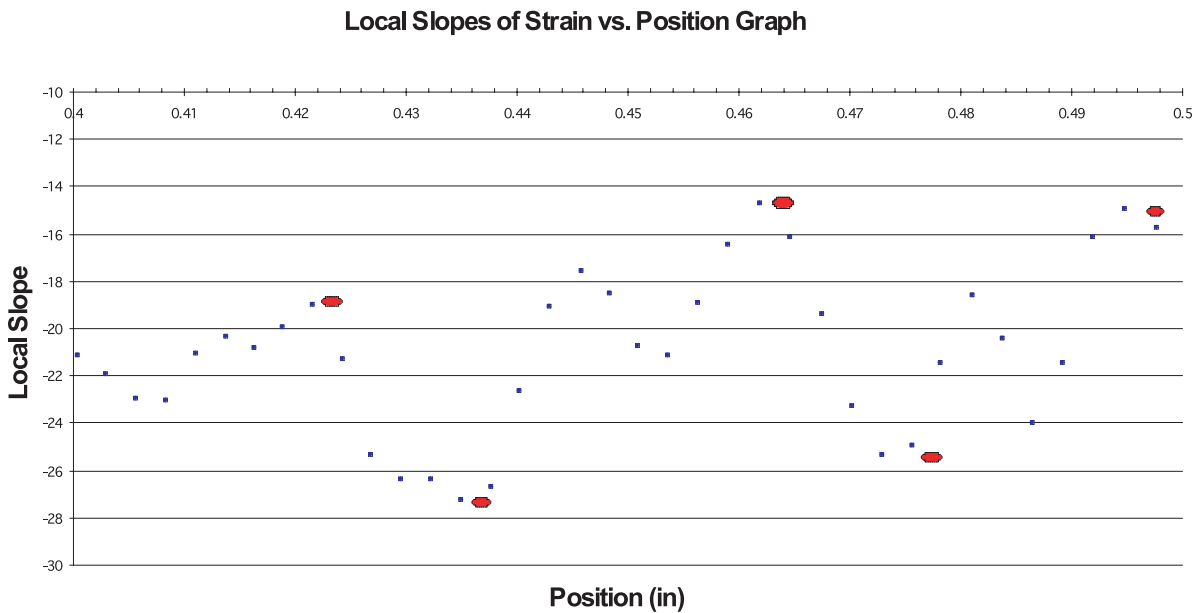
Figure 2: Graph of local slope vs. position for use in method 2. The red circles represent the position of a critical strain determined using method 2. These position values are then related to the strain data to obtain the strain percent.

Critical Strains Found in a Brass Tensile Specimen (Strain percent 7-20)
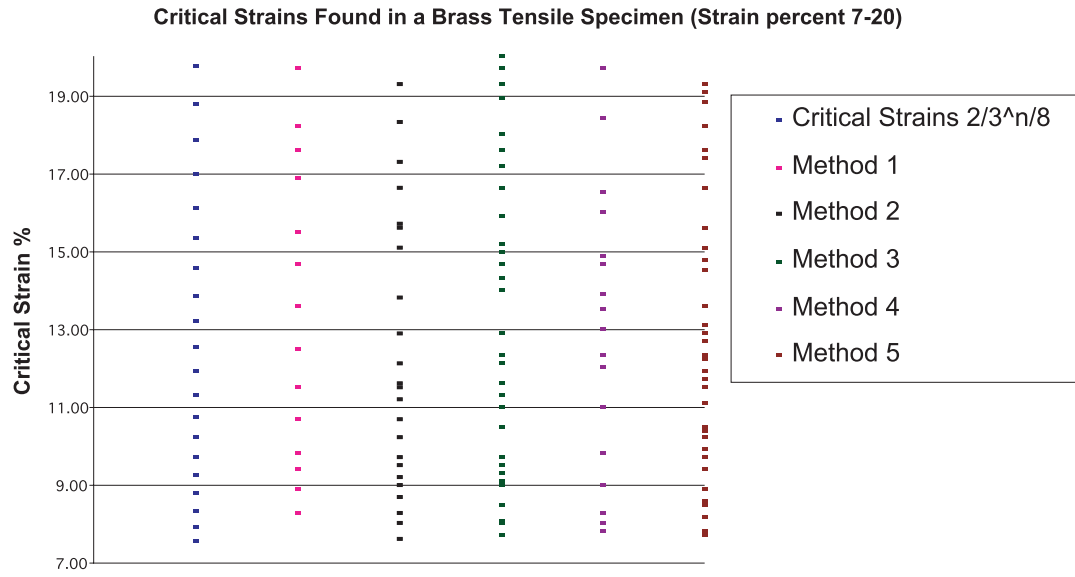
Figure 3: Graph of critical strains found using each method and hypothesized critical strains found using the $2/3^{n/8}$ equation. Strains range from 7% - 20%.

Critical Strains Found in a Brass Tensile Specimen (Strain percent 20-40)
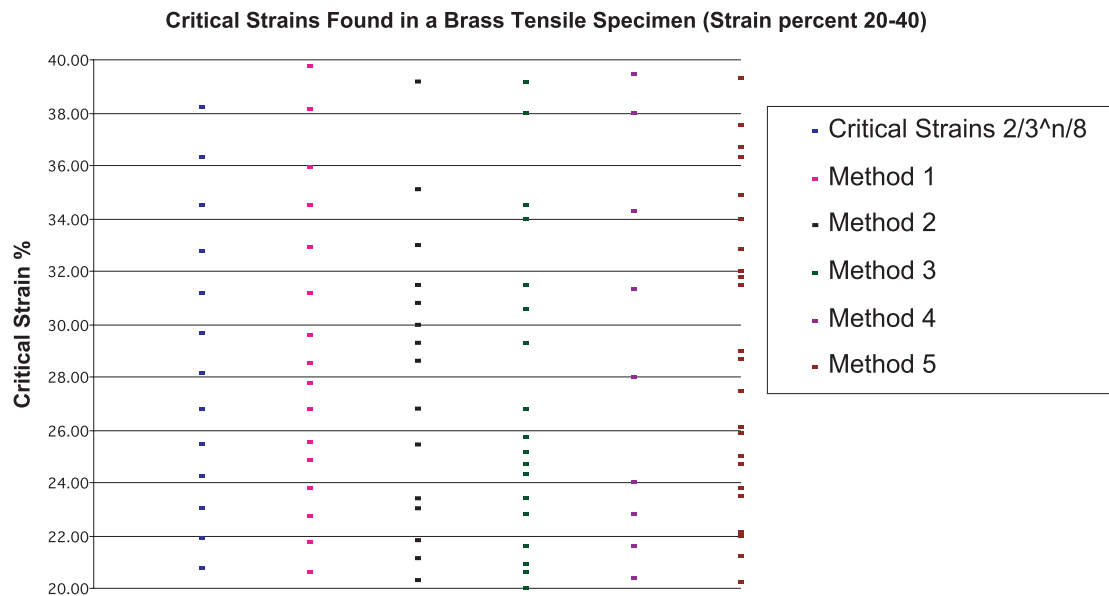
Figure 4: Graph of critical strains found using each method and hypothesized critical strains found using the $2/3^{n/8}$ equation. Strains range from 20% - 40%.

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Critical Strains Found in a Brass Tensile Specimen (Strain percent 40-80)
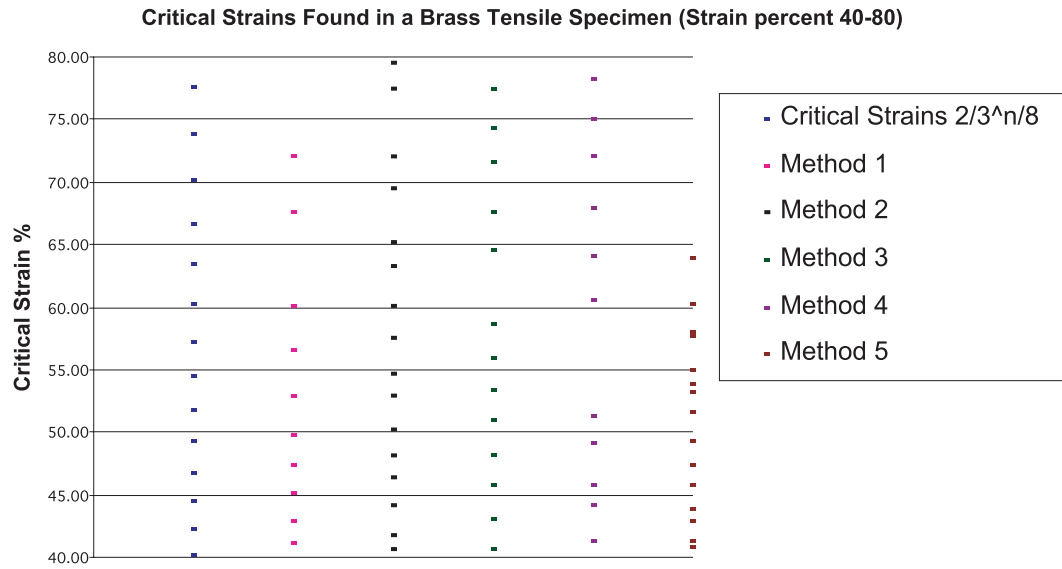
Figure 5: Graph of critical strains found using each method and hypothesized critical strains found using the $2/3^{n/8}$ equation. Strain range from 40% - 80%.

MANUFACTURING STRANDED COMPONENTS IN BRITTLE MATERIALS USING WOLLASTON WIRE
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Manufacturing Stranded Components in Brittle Materials Using Wollaston Wire

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Key Words

Alloy, Brittleness, Ductility, Shape Memory Effect, Diffusion, Shrink Fit, Cast, Wire Drawing, Swaging

Prerequisite Knowledge

Introduction to Materials Science, Manufacturing of Engineering Materials

Objective

- To engineer a new and cost effective technique for manufacturing brittle alloy wire

Equipment and Materials

- Pure Copper, Zinc, Aluminum
- Oxy-Fuel Torch
- Graphite Crucibles, Molds, Tongs
- Power Wire Drawing Machine and Accessories

Introduction

Brittleness is a material condition of limited ductility in certain metals and alloys, plastics, and ceramics. For metals and alloys, brittle behavior is manifested in certain crystal structures with limited slip systems that cause the material to fracture at comparatively low strain values. Different alloying elements and inclusions also influence the structure and ductility of metals and alloys. Foreign atoms and particles inhibit dislocation movement during plastic deformation and therefore lead to early fracture. Certain metals and alloys are inherently brittle; they fracture at relatively low strain values, and do not perform well under tensile loads. As a result, brittle metals do not withstand large amounts of cold work during forming operations.

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Manufacturing processes for brittle materials may be multi-step and costly. Despite processing difficulties, many brittle alloys remain of interest for use in engineering applications. Most of the superconducting alloys are brittle; likewise, superelastic alloys and alloys that show the shape memory effect are often brittle.

The shape memory effect is a phenomenon in which a specimen is deformed in a low temperature martensite phase and upon heating to a critical temperature, regains the shape of its parent phase. Shape memory alloys are currently used and have the potential for great advancements in bio-medical and industrial applications. However, processing difficulties prohibit large-scale availability of some of these alloys, especially in wire form. Wire drawing operations typically require a succession of annealing heat treatments, which counteract loss of ductility due to the work hardening in the alloys. An inherently brittle alloy requires more annealing steps to survive the drawing process without breakage than ductile alloys. Each additional processing step increases the cost of manufacturing. Our research is concerned with engineering a new and cost effective technique to overcome the limitations of brittleness and to draw these alloys into wire form.

Our project design is derived from the work of the scientist and metallurgist William Hyde Wollaston (1766-1828). He is credited for the discovery of platinum, palladium, and rhodium. His interest in improving astronomical equipment led him to attempt to draw platinum into extremely fine wire – as fine as 1/20,000 inches in diameter. This reduction in cross section was unheard of in his day, and he was successful using a method where he surrounded the platinum with a ductile ring of silver. When a preform is pulled through a die, it undergoes tensile and compressive forces at the die interface that cause a plastic flow in the material. The end result is a reduction in diameter and elongation of the specimen. In Wollaston's wire preform, the silver acted as a ductile outer layer that withstood the drawing process better than the platinum, while transferring the drawing forces into the platinum. The platinum center and the surrounding silver decreased size proportionately during the reductions, and the platinum was drawn without breakage. The silver was removed with acid after the final pass through a wire die, leaving extremely fine platinum wire.

Our research applies the Wollaston technique for an inherently brittle Cu-Zn-Al shape memory alloy. In our approach the ductile copper will surround the more brittle components of a Zn-Al alloy. The final drawn product remains as a two-part system with copper on the outside. A diffusion process will be used to produce a homogeneous ternary Cu-Zn-Al alloy. This technique provides a new method of drawing these inherently brittle materials while they are more ductile in their component form, thereby reducing expenses of intermediate annealing.

Procedure

The process for demonstrating the effectiveness of Wollaston's technique for manufacturing brittle shape memory alloys follows:

1) Produce a composite rod according to desired percentages of each element by weight.

2) Reduce the rod to wire.

3) Heat-treat and test the product.

      a. Inter-diffuse atoms of each element for homogeneity

      b. Test for shape memory effect

The first step was to choose a system with limited ductility that has been known to exhibit the shape memory effect.[1] We selected the alloy: 6% Al, 22.7% Zn, 71.3% Cu. Copper based shape memory alloys can find uses in several engineering fields. We have a specific interest in researching their performance in biomedical applications such as guide-wires in stent deployment. There are some disadvantages to using the shape memory effect with copper-based alloys in biomedical applications. Copper alloys are not biocompatible for long-term use, but they are cheaper and more radio-opaque than traditional Ni-Ti systems. Combined with the success of our research, this manufacturing technique might provide incentive for further research with copper based shape memory alloys.

In the process of our experiment, we developed several manufacturing alternatives to produce a composite blank. This consisted of an Al-Zn alloy in the center, surrounded by copper. The dimensions of each blank are dependent on the percentages of each element by

weight.[2] The first manufacturing alternative was to cast a rod of Al-Zn and shrink fit it inside a hollowed out copper rod. Using an oxy-fuel torch, we melted aluminum and zinc together in a 1000-gram sample to obtain the molten Al-Zn alloy. We then cast this into a die and later shrink fitted this piece into a hollow rod of pure copper.[3] The second alternative was to pour molten Al-Zn into thick walled copper pipe, and allow it to solidify.[4] This method avoided the shrink fit process and reduced the number of steps to produce a composite blank. The third alternative used a vacuum pump to suck molten Al-Zn into a copper tube, and allow it to solidify.[5] The small starting diameter of the copper tube brought this preform closer to final wire drawing size than the other preforms, which were much larger than the maximum wire die size available to us, and required swaging first. We considered and did not experiment with another method, which was to cast a rod of Al-Zn and electroplate the outside with copper.

The final step in our process was completed due to the assistance of Johnson Matthey, Ltd., a platinum metals company in Pennsylvania. The manufacturer attempted to draw the three pieces made from the three manufacturing alternatives into wire. [6]

The diffusion studies of this experiment will be completed in future work. These include inter-diffusing the elements in the wire to create a homogeneous alloy. We will observe this with x-ray diffraction and then test for the shape memory effect.

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[1] Fig. 1
[2] Sample Calculations
[3] Fig. 2
[4] Fig. 3
[5] Fig. 4
[6] Table 2

Results

Three Manufacturing Alternatives

Test Piece	Creation Details	Target Composition	Starting		Composition Dependent Dimensions		Process	Successful?
			ID (in)	OD (in)	ID (in)	OD (in)		
Shrink Fit	6/12/03, Prof. Pond's Lab	14%Al, 26.3% Zn, 59.6% Cu	.501	.134	-	-	JM* Swage, Draw	No
Vacuum Tube Cast	7/14/03, Prof. Pond's Lab - Molten metal traveled ~ 6 inches up the Cu tube.	6%Al, 22.7% Zn 71.3% Cu	.132	.060	.132	.038	JM Draw	Partially
Thick Wall Copper Casting	7/14/03, Prof. Pond's Lab - Cu pipe 14 in long, preheated 400 °C.	6%Al, 22.7% Zn 71.3% Cu	.4375	.4125	.4375	.4175	JM Swage, Draw, Anneal	Yes

Table 1   * JM abbreviates Johnson Matthey, Ltd.

Responses to Swaging and Drawing

Shrink Fit Piece	Vacuum Cast Alloy	Thick Walled Copper
The center Al-Zn core fractured inside of the copper during swaging and on the first attempt at drawing, the Al-Zn core detached from the copper.	This went through four dies, but after many attempts at drawing with various variables, we determined that the breakage was too severe to generate long wire. Approximately 10% reduction.	Swaging and drawing worked well. We reduced the cross sectional area by 71% without intermediate annealing steps. Stress relief steps were provided, but not confirmed as necessary to assure final product.

Table 2

Wire Forming Schedule for Thick Walled Copper Piece

Process Step	Reduced Diameter (inch)	Percent Reduction (%)	Percent Reduction in Area (%)
Swage	0.850 (starting)		
	0.760	20.1	
	0.685	18.7	
	0.641	12.4	
	0.591	15.0	
	0.544	15.3	
	0.494	17.6	
	0.460	13.2	70.7
*Argon Batch Stress Relief (30 min, 650° F/ 343° C)	-	-	-
Draw	0.460	-	
	0.410	20.6	
	0.360	23.0	
	0.325	18.5	
	0.289	21.0	
	0.258	20.3	90.7
*Argon Batch Stress Relief (30 min, 650° F/ 343° C)	-	-	-
Draw	0.064	-	99.4
*Continuous Air Stress Relief (30 min, 650° F/ 343° C)	-	-	-
Draw Series	0.032	-	99.9

Table 3   *Johnson Matthey recommended that we stress relieve after this amount of work hardening to assure there is no fracture of the wire.

Comments

The shrink fit piece required machining to ream and open the copper according to our calculated dimensions. This piece differs in its target composition from the other two; however, it corresponds to another shape memory alloy. Due to the high core to copper ratio, the inner alloy fractured because the copper annulus was too thin to withstand the forces required to deform the centerpiece. Also, the bond between the core and copper was not strong enough to keep the core from detachment during drawing. This indicates that our shrink fit was not an efficient bonding technique for this procedure.

Direct casting also posed a problem because of solidification shrinkage of the core. In the case of the thick wall copper assembly, the center piece was not bonded to the copper wall after the inner cast cooled. However, this piece withstood the swaging process because the copper closed around the ends of the pipe during swaging. This and the shrink fit piece both had weak bonds between the core and copper, but one performed better than the other because of the amount of copper surrounding the core.

The copper tube composite was relatively easy to make with the aid of the vacuum pump, but the molten metal only traveled a maximum vertical distance of six inches in the tube before it solidified. This is not a good method if a longer blank is desired. Again, due to a high core to copper ratio, this composite did not withstand many reductions in area during wire drawing without fracture. This blank was not at its composition dependent dimensions before we reduced its cross section. The calculations show that ~ 0.040 inch of the copper needed to be dissolved to reach the target composition. In retrospect, if more of the copper had been dissolved before drawing, the piece probably would not have withstood any reductions through the dies. Given the limited size of this piece, no further work has been attempted on the method.

The heavy wall casting was rendered to wire form. The heat treatment of the copper before casting may have also aided in the prohibition of casting defects that lead to breakage. Most of its success in area reduction however, is attributed to its proportionally thick wall of copper that transferred drawing loads and protected the inner core from fracture.

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Further thought needs to be given to maintaining the proper dimensions for the target alloy, both during tapering exercises where material is lost, and in dissolving excess copper off after wire drawing. There also needs to be further consideration of equipment and materials. The copper pipe used for the thick walled piece was difficult to obtain. Typically copper tubing on the market does not exceed a wall thickness of 0.065 inches. This pipe had an unusual wall thickness of 0.4125 inch, and it probably was produced more than fifty years ago.

The modification of Wollaston's process was successful in to forming wire of brittle material. In part two of this experiment, we will demonstrate the shape memory effect in the target alloy.

Figures
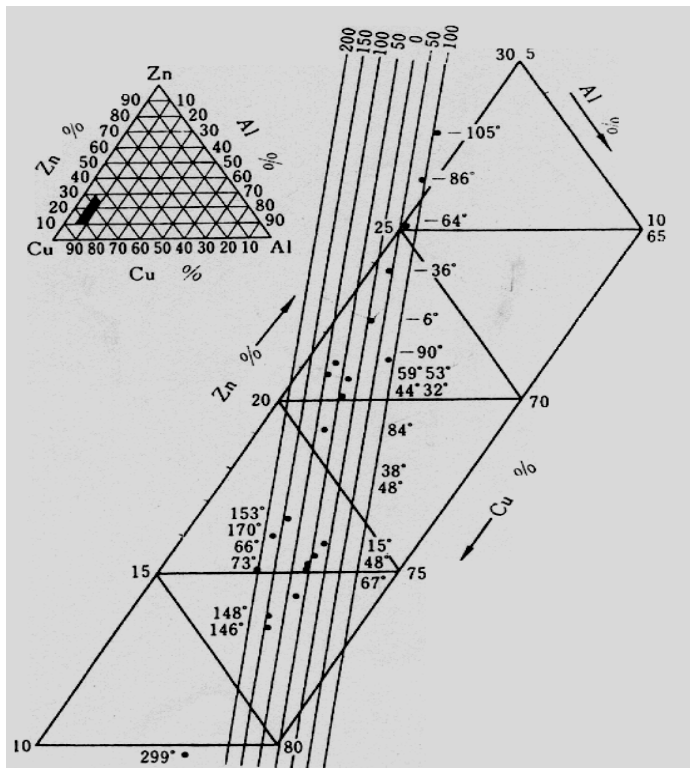
Fig. 1 Relation between Martensite start temperature and alloy composition in Cu-Zn-Al SMAs (Otsuka\ Wayman 100)
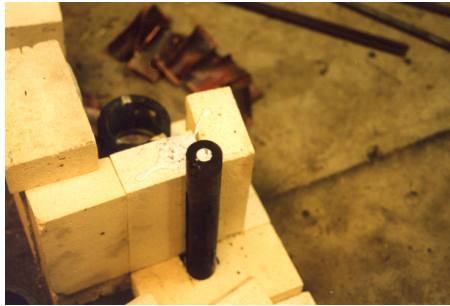
Fig. 2 Al-Zn Alloy Cast 6/12/03

Fig. 3   Pour of Molten Al-Zn
         into Copper Pipe 7/14/03
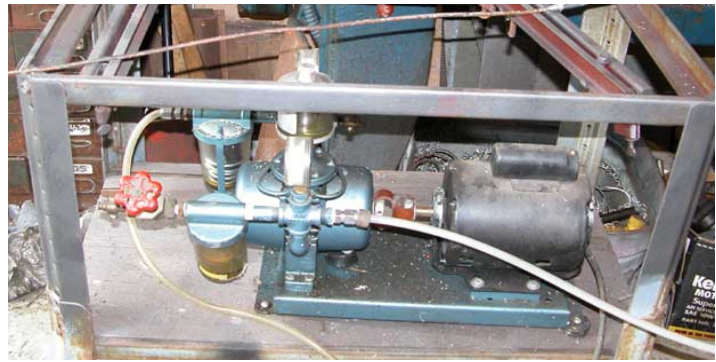
Fig. 4 Vacuum Pump and Copper Tube 7/14/03
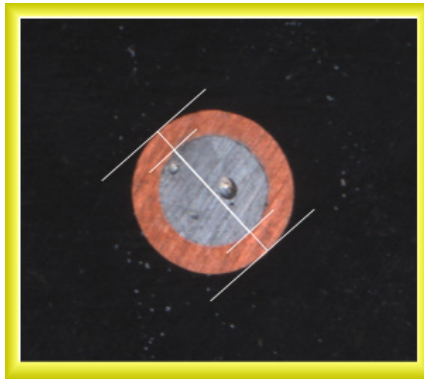
OD = 0.192 inch (4.88 mm) Cu
ID = 0.132 inch (3.35 mm) Al/Zn
Fig. 5 Mounted Vacuum Cast Composite

Sample Calculations

$\Delta_{zn} = 7.13$ gm\cc   Target Alloy:

$\Delta_{al} = 2.69$ gm\cc   6% Al, 22.7% Zn, 71.3% Cu

$\Delta_{cu} = 8.96$ gm\cc

$\Delta_{zn + al} = [(6\backslash 28.7)(2.69) + (22.7\backslash 28.7)(7.13)]$ gm\cc $= 6.202$ gm\cc

Target Dimension for Thick walled Cu Piece:

$Br_{id}^2 \, \Delta_{zn + al} = m_{zn + al}$

$B (r_{od}^2 - r_{id}^2) * 1cm * \Delta_{cu} = m_{cu}$

$m_{cu} \backslash m_t = 0.713$

$m_{cu} = .713 (m_{cu} + m_{zn + al})$

$.403 \, m_{cu} = m_{zn + al}$

$m_{cu} = (1 \backslash .403) Br_{id}^2 * 1cm * \Delta_{zn + al}$

$m_{cu} = (1 \backslash .403) Br_{id}^2 * 1cm * (6.202$ gm\cc), for $r_{id} = .556$ cm

$m_{cu} = 14.93$ gm \ cm length

$\mathbf{r_{cu}} = m_{cu} \backslash \Delta_{cu} B = .530$ cm $= 0.209$ inch

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For the copper tube used in the vacuum cast: $\mathbf{r_{cu}} = m_{cu} \backslash \Delta_{cu} B = .048$ cm $= 0.019$ inch

For the shrink fitted piece: $r_{cu} = 0.067$ inch

Percent Reduction in Area $= \dfrac{A_o - A_f}{A_o} * 100\%$

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ETHANOL-WATER PHASE DIAGRAM
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Ethanol-Water Phase Diagram

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ABSTRACT: A procedure is described for constructing a partial phase diagram for the ethanol-water system. The water-rich portion of the diagram was investigated for concentrations ranging from 70 to 100 vol% by placing the solutions in an immersion cooler. A digital storage oscilloscope was used to record cooling and subsequent warming curves obtained from continuous-time thermocouple measurements. The imposed cooling rate tended to overwhelm the latent heat of fusion release for the system, making determination of arrests and breaks in the cooling curves (normally used for metallic systems) unreliable. However, the energy balance on warming was much more favorable, allowing slope changes in the resultant curves to be analyzed for temperatures defining the liquidus and solidus lines. The experimental determination of the liquidus line is compared with literature results. In addition **(optional activity),** heat of fusion correlations are made for melting point and various material families; further, the validity of Richards' rule is assessed.

KEY WORDS: phase diagram, liquidus line, solidus line, cooling curve, warming curve, latent heat of fusion, Richards' rule, ethanol, water.

PREREQUISITE KNOWLEDGE: sophomore-level undergraduate laboratory experiment requiring basic knowledge of phase diagrams as described in an introductory materials science course and accompanying laboratory course; also suitable **(with optional activity)** as an upper-level undergraduate experiment relating to a phase transformations in solids course.

OBJECTIVES:

(a) Experimental Goals:

1. to measure cooling/warming curves for various ethanol-water mixtures;
2. to measure arrests and breaks in the cooling/warming curves allowing determination of the liquidus and solidus lines for the phase diagram; and
3. **(optional activity)** to obtain material property (i.e., latent heat of fusion) correlations.

(b) Learning Goals:

1. to become familiar with phase diagram features;
2. to become familiar with how boundaries in phase diagrams are determined experimentally;
3. to become familiar with the thermal energy balance, involving latent heat of fusion, that occurs during arrests and breaks in the cooling/warming curves; and
4. **(optional activity)** to become familiar the process of correlating handbook values of material properties for various materials.

EQUIPMENT AND MATERIALS: (1) Digital thermometer (Omega model 115 JC); (2) Type J (iron/constantan or iron vs. copper nickel) thermocouple (with test tube adaptor); (3) Immersion cooler (Brinkmann Lauda model IC-8); (4) Digital storage oscilloscope (Nicolet model 310); (5) Test tubes; (6) Deionized water; (7) Ethanol (95 vol%).

SAFETY PRECAUTIONS: Handling test tube specimens exposed to temperatures below the freezing point of water requires care, and normal safe laboratory practice should be followed. Test tube specimens should be slowly placed in and removed from the immersion coil to avoid possible breakage. (Instructor Note 1)

A greater possibility of test tube breakage can occur because of ice formation around the coil outside the test tube placing it in compression. (Instructor Note 2)

INTRODUCTION: A binary phase diagram [1] is a plot of temperature, T, vs. mole fraction of the "B" component, x_B, or sometimes T vs. weight percent of the "B" component, % W_B, and shows the results of a series of experiments that determine the equilibrium constitution at each T and x_B. The constitution of a binary material is described by three factors: (1) the phases present; (2) the amount of each phase; and (3) the composition of each phase. A phase diagram is usually obtained by measuring slow cooling rate curves (i.e., T vs. time, t) for materials of various compositions beginning in the liquid state. [2-4] The pressure remains constant, typically 1 atm. Analysis of the cooling rate data together with microstructural analysis of the solidified materials at room temperature allows the so-called fields (regions where the number of the phases and their identity are constant) of the phase diagram to be established. (Instructor Note 3)

Considering metallic systems, binary alloys are typically created by melting two (2) pure metallic components and stirring to make them homogeneous while in the liquid state. Binary alloys can be classified [5] as having one (1) of four (4) structural types once completely transformed to the solid state:

(1)   single solid solution (e.g., Cu-Ni, Ref. [6]);
(2)   two separated nearly pure components (e.g., AI-11 wt % Si, Ref. [7]);
(3)   two separated solid solutions (e.g., Cd-60 wt% Zn, Ref. [8]); and
(4)   a chemical compound and a solid solution (e.g., AI-4 wt% Cu, where 0 designates
         $CuAl_2$, Ref. [9]).

This experiment involves the heterogeneous equilibrium that exists between solid and liquid phases in a non-metallic system (ethanol-water) and illustrates the relatively unusual use of warming curves to determine a portion of the phase diagram. Warming curves, rather than cooling curves, are analyzed because the immersion cooler being used provides too high a cooling rate for equilibrium conditions to be reached. On warming, the conditions are established.

The temperatures at which the solid begins and finishes forming are given by the liquidus and solidus lines, respectively, as indicated in Fig. 4.3, Ref. [10]. The liquidus line separates the single-phase liquid field from the two-phase (liquid + solid) field and is the locus of points that defines the commencement of freezing as a function of composition. The termination of freezing for various compositions is given by the solidus line which separates the two-phase (liquid + solid) field from the single-phase solid field. The particular temperatures for these phase boundaries are observed as changes in the slope of temperature vs. time in the warming curves. A slower rate of warming is observed when a solid phase commences melting because the heat absorbed by melting partly offsets the heat gained by conduction and radiation from the warmer surroundings. The absorbed heat is referred to as the latent heat of fusion and is the quantity of energy required to transform the ordered (crystal lattice) solid into a disordered (amorphous) liquid.

The primary purpose of this experiment is to determine a portion of the ethanol-water phase diagram. This system was chosen because it is environmentally friendly, not having toxicity problems that many metallic systems have. (Instructor Note 4) In addition, knowledge is acquired about the properties and behavior of materials different from metallic systems and having a distinct type of bonding (hydrogen).

PROCEDURE:

A. EXPERIMENTAL

A Nicolet digital storage oscilloscope is used to record and retain the cooling/warming curves for a series of ethanol-water solutions placed in test tubes that are inserted in the coil of a bench-top immersion cooler. A test tube adaptor serves as a stopper while centering a Type J thermocouple in the solution to be studied; data, appearing as millivolts versus seconds, are obtained using an Omega digital thermometer. These voltages are taken from an analog output available from the back of thermometer and can be converted to T, °C, using the factor 1 mV/°C. (Instructor Note 5)

The concentrations of the ethanol/water solutions to be studied (Instructor Note 6) are as follows:

vol% pure water	100	95	90	85	80	75	70
vol% 95/5 ethanol/water	0	5	10	15	20	25	30

Record measurements and any relevant observations in a laboratory notebook with appropriate drawings.

1. Obtain the cooling/warming curve for one solution containing ethanol. Sketch the curve and label its basic features. Examine the warming curve to determine the voltage levels at which slope changes occur.
2. At least one cooling/warming curve was obtained beforehand for each solution concentration including pure water. Examine the curves for the other ethanol solutions and carefully note how they differ. Sketch the curve for pure water and label its basic features.
3. Referring to the sketches of the curves for pure water and the experimentally determined curve for the ethanol solution, carefully note similarities and differences.
4. **(Optional Activity)** Using the Handbook of Chemistry and Physics [11,12] or other sources, record values of melting temperature and latent heat of fusion for the following materials by family [13]:

> Metals: aluminum, bismuth, copper, indium, iron, lead, tin, and zinc;
> Inorganic compounds: aluminum oxide, iron (II) oxide, magnesium oxide, and water; and
> Organic compounds: ethanol, glycerol, and methanol.

B. ANALYSIS

Perform the following analyses and respond to any questions as completely as possible being sure to show all of your work and reasoning as partial credit can be earned.

1. Warming curve assessment:

   a. Carefully draw and completely label a schematic of a warming curve for (1) the ethanol-water solution and (2) pure water. Be sure to explain what is happening to the material (e.g., warming; undergoing phase transformation) at each distinct portion of each curve.

   b. Convert the voltage levels at which slope changes occur in the ethanol-water solution warming curve to temperatures using 1 mV = 1° C.

2. Partial phase diagram determination:

   a. Using density values of 0.998 and 0.788 g/ml for water and 95 vol% ethanol, respectively, at 22° C, calculate the mole fraction of water (i.e., component B) for all of the solutions studied (Instructor Note 7). Note: this calculation is facilitated by using a basis of 100 ml total volume of solution. Then, the separate volumes are converted each to masses, g, and then moles, n. The mole fraction of water is calculated using
   $$X_B = n_B/n_{total} = n_B/(n_A + n_B). \hspace{3cm} (1)$$

   b. Plot temperature versus mole fraction of water for both the liquidus and solidus data obtained for all of the solutions studied. Connect the points smoothly and label both sets of data. Also label the fields present in this portion of the ethanol-water phase diagram. Note: this plot should occupy a major portion of the graph paper and the mole fraction axis should range from 0.85 to 1.0.

3. **(Optional Activity)** Latent heat of fusion correlations:

   a. Prepare a plot of latent heat of fusion, cal/mole, versus melting temperature, K,

for the various materials by family. Assess any correlations that exists for a given family and between families of materials.

b. From chemical thermodynamics [14], the solid and liquid phases have the same energy at the melting temperature, T_M:

$$G_S = G_L, \qquad\qquad (2)$$

where G_S and G_L are the Gibbs free energies of the solid and liquid phases, respectively.

The free energy is defined as:

$$G = H - TS, \qquad\qquad (3)$$

where H is the enthalpy, T is temperature, and S is the entropy.

Hence, at the melting temperature:

$$H_S T_M S_S = H_L T_M S_L \qquad\qquad (4)$$

Furthermore, the latent heat of fusion, 0 HF, is the difference in the enthalpies:

$$\Delta H_F = H_L - H_S. \qquad\qquad (5)$$

Combining Eqs. (4) and (5) yields an expression for the entropy of fusion, ΔS_F:

$$\Delta S_F = S_L - S_S = \Delta H_F / T_M,($$

which provides a quantitative assessment of the decrease in order a material undergoes as the solid transforms to liquid. An empirical correlation known as Richards' rule states that 0 *SF* z' constant z 2 cal/mole K for most metals. [15]

Tabulate computed Δ *SF* values for the various materials listed above and assess the validity of this correlation.

COMMENTS with Sample Data Sheet and Plot:

All of the experimental steps were typically performed at least twice to verify that the results are reasonably reproducible. The data appearing in this section are considered to be representative.

Warminiz Curve Characteristics: The complete experimental cooling/warming curves (as recorded on the oscilloscope) for 90/10 water/95% ethanol by volume and pure water appear as analog plots in Figures 1 and 2, respectively. In both cases, there is no distinct (or reproducible) break or arrest in the cooling curve that would allow the liquidus and solidus temperatures to be determined. However, the warming curve for the ethanol solution has an extended portion with essentially constant slope corresponding to the occurrence of melting. The first break in this linear portion occurs at -7.90 mV (° C), -532.5 s, corresponding to the onset of melting and hence providing the solidus temperature. A second break is observed at -1.75 mV (° C), -116.5 s where melting ceases and the liquidus temperature is defined for this particular solution. The warming curve for pure water shows a prominent arrest at nominally 1 mV (° C) beginning at -986.5 s and ending at -201.0 s, corresponding to melting. Here, it should be noted that a small positive drift commenced at -403.5 s, and the uncertainty in temperature quoted by the manufacturer is ± 1° C.

Phase Diagram Construction: The measured liquidus and solidus temperatures as a function of water mole fraction appear in Table I and are plotted in Figure 3. Both curves show a continuous decrease in temperature with decreasing mole fraction, thus revealing the expected freezing point depressant activity of ethanol in water. The difference in the liquidus and solidus temperatures was relatively modest, varying from 4.0 to 8.4° C for mole fractions ranging from 0.985 to 0.911; however when the mole fraction decreased to 0.890, this difference exceeded 13.5° C, which is inexact because the solidus temperature was not reached before the minimum temperature that can be provided by the immersion cooler was achieved. The liquidus and solidus temperature lines provide the boundaries for the relatively small two-phase (liquid + solid) field.

Literature Comparison: For the water mole fractions of interest, there is reasonable agreement (Figure 4) between measured liquidus temperatures and temperatures defining the (liquid/solid) phase boundary in the ethanol-water phase diagram reported by Ott, Goates, and Waite [16] under much more controlled experimental conditions providing smaller experimental uncertainty. They also discuss their difficulty in obtaining equilibrium conditions even when using warming curves which may explain why only a single line appears in the phase diagram rather than the expected liquidus and solidus lines. Additional literature results appear in the Handbook of Chemistry and Physics [17], providing somewhat
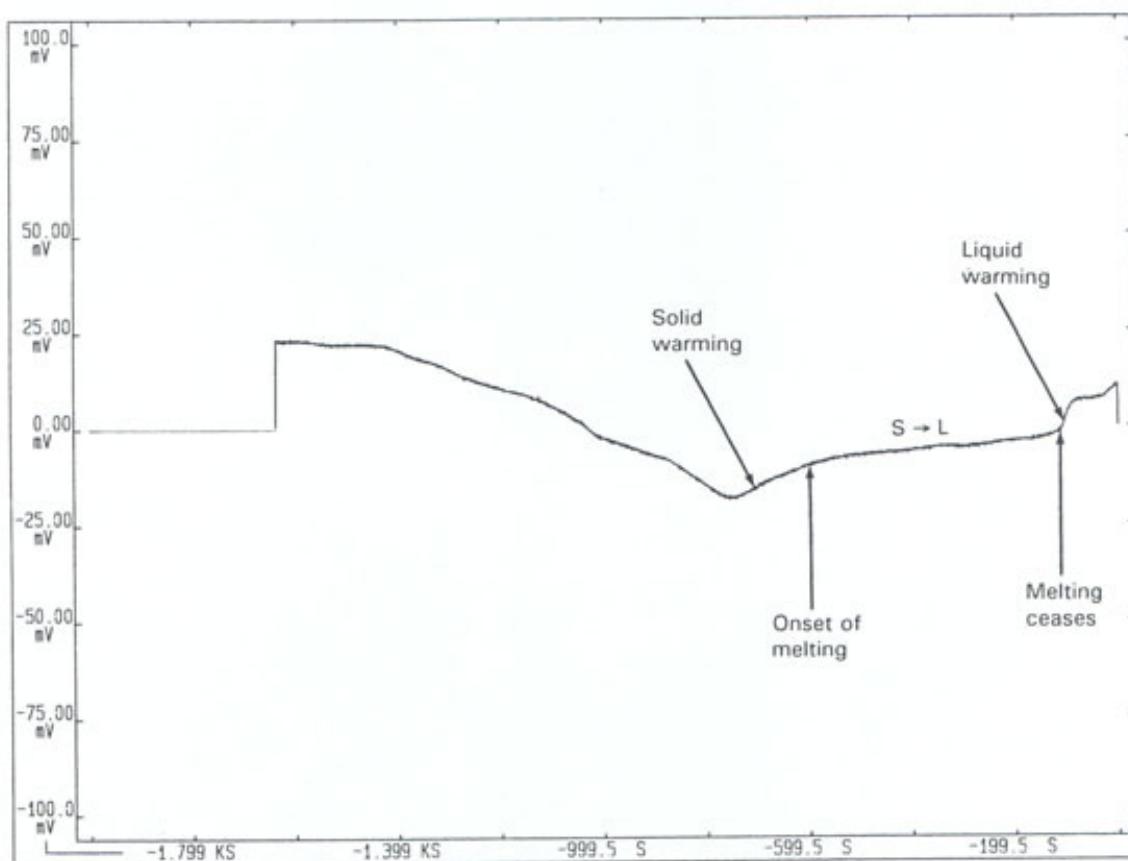
Figure 1. Oscilloscope trace of cooling/warming curve for 90/10 water/ 95% ethanol by volume (run #3).
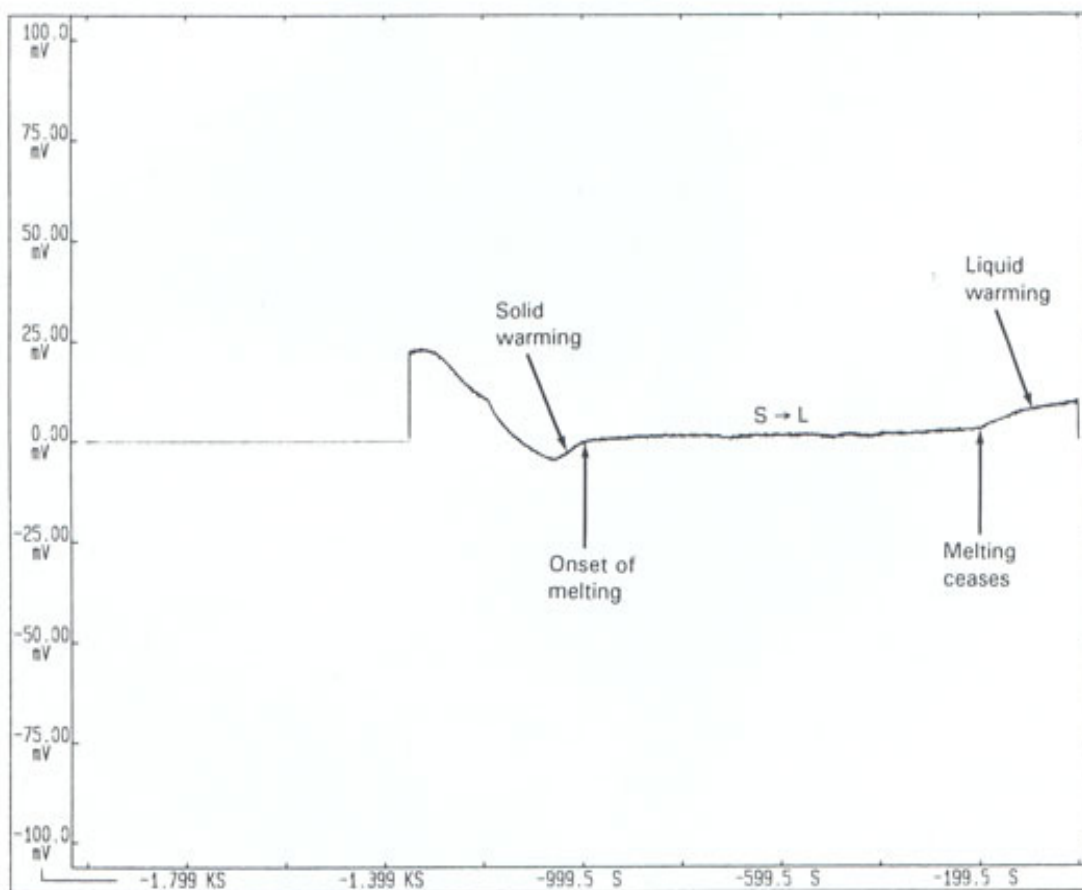
Figure 2. Oscilloscope trace of cooling/warming curve for pure water (run # 2).

Table I. Transformation Temperatures for Freezing Ethanol-Water Solutions

Run #	Concentration (Vol % H20/Ethanol)	Mole Fraction	Liquidus T* (° C)	Solidus T* (° C)
2	100/0	1.00	+ 1	+ 1
7	95/5	0.985	-1.5	-6.2
32	95/5	0.985	-1.7	-7.0
3	90/10	0.969	-1.8	-7.9
29	90/10	0.969	-2.0	-9.3
13	85/ 15	0.952	-4.5	-12.5
12	80/20	0.933	-7.3	-14.8
18	75/25	0.911	-11.4	-19.8
15	70/30	0.890	-15.1	< -28.6

*The temperature measurement uncertainty is ± 1 ° C.
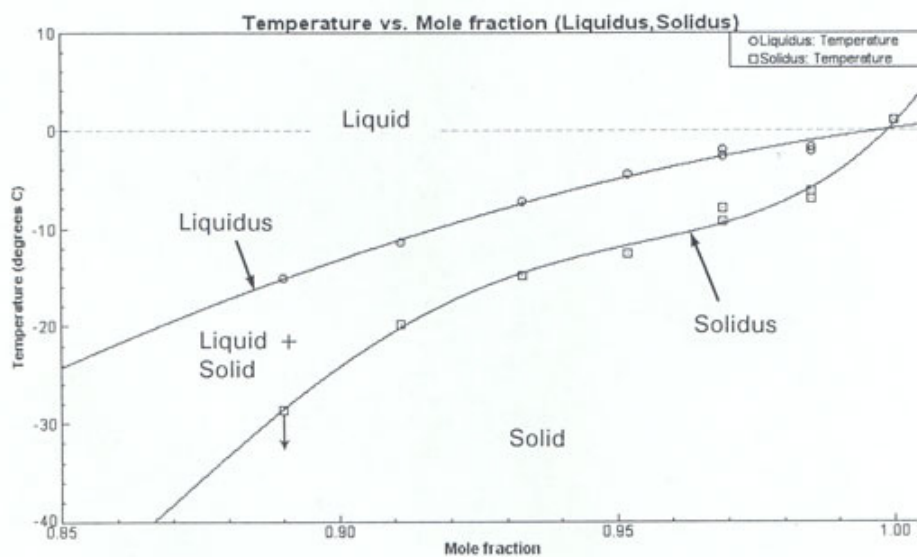
Figure 3. Partial ethanol-water phase diagram.
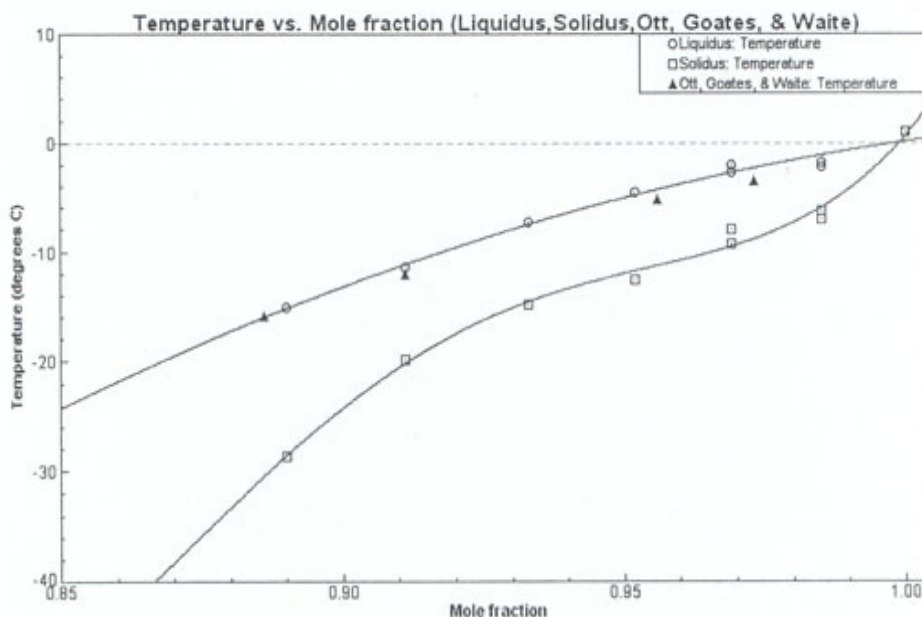
Figure 4. Comparison between measured liquidus temperatures and corresponding temperatures obtained by Ott, Goates, and Waite.

better agreement (Figure 5). 1n both instances, it is important to note that the greatest discrepancies occur at small freezing point depressions where experimental uncertainty has the largest relative effect.

Correlations Using Latent Heat of Fusion: Values of T_M, ΔH_F, and ΔS_F for the various materials listed above under metals, inorganic compounds, and organic compounds are given in Table II. A plot of ΔH_F versus T_M appears in Figure 6 showing the general trend that heat of fusion increases as melting temperature increases as expected since melting temperature provides a means to gauge the bond strength of a material. For metals, the trend in the plot is essentially linear with a fair bit of scatter around 500 K. Water, ethanol, and methanol fall nicely with the quasi-linear behavior. Significant departures from linearity are observed for the high melting inorganic compounds (two of which have ΔH_F values of uncertain reliability) and the more complicated alcohol, glycerol. Metals have the lowest entropy of fusion values, whereas inorganic and organic materials with more complicated lattices [19] have significantly higher values. For the range of materials provided in Table II, it is concluded that Richards' rule applies reasonably well for cubic metals. However, the rule has limited general application [20] and does not hold for some non-cubic metals and particularly for non-metallic compounds.

INSTRUCTOR NOTES:

1. It is important to demonstrate to students how to operate the immersion cooler and particularly the digital storage oscilloscope prior to commencing the actual cooling portion of the experiment. The ethanol-water concentrations used in this experiment were selected to cover the range of cooling temperatures that the immersion cooler can provide. Students also need to be shown how to handle samples subjected to temperatures below room temperature. See **SAFETY PRECAUTIONS.**

2. It has been suggested [21] that the water bath for the immersion cooler be replaced with say a 50/50 ethanol-water solution so ice does not form around the immersion coil and outside the test tube in order to lessen significantly the possibility of breakage as mentioned under **SAFETY PRECAUTIONS.**

3. Determining the temperatures for the commencement and termination of phase transformations for binary alloys does not establish which of the four types listed in the Introduction are present. This can only be determined by examining the resultant macrostructure/microstructure using reflected light microscopy techniques. This involves sectioning alloys of varying composition and polishing an exposed flat surface until the finish is mirror-like. The polished surface is then etched in a controlled manner typically using a weak acid to reveal various features. The etching is successful because the rate is different for each feature present such as grain boundaries, precipitate particles, and phases with different chemical compositions. The microscopic study of surface-prepared metallic specimens is known as metallography and is widely practiced as a research and quality control tool.
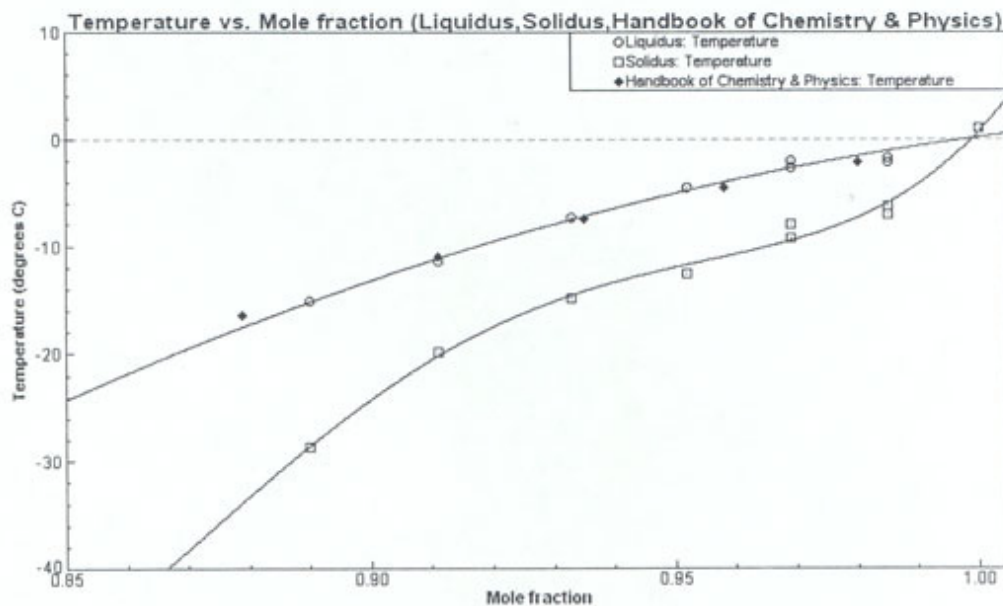
Figure 5. Comparison between measured liquidus temperatures and corresponding temperatures reported in the Handbook of Chemistry and Physics.

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Table 11. Values of Latent Heat of Fusion and Entropy of Fusion for Various Materials

Material	Crystal Structure	Melting Temperature (K)	Heat of Fusion (cal/mole)	Entropy of Fusion (cal/mole K)
Metals				
Aluminum	Face-centered cubic	933.5	2550	2.73
Bismuth	Rhombohedral	544.5	2505	4.60
Copper	Face-centered cubic	1356.6	3110	2.29
Indium	Tetragonal	429.8	781	1.82
Iron	Body-centered cubic	1808.2	3560	1.97
Lead	Face-centered cubic	600.7	1224	2.04
Tin	Tetragonal	505.1	1720	3.41
Zinc	Hexagonal close-packed	692.8	1595	2.30
Inorganic compounds				
Aluminum oxide	Hexagonal or Wurtzite-like [18]	2318.2	(26,000)	(11.2)
Ferric oxide	Cubic	1693.2	(7700)	(4.55)
Magnesium oxide	Cubic	3073.2	18,500	6.02
Water	Hexagonal	273.2	1436	5.26
Organic compounds				
Ethanol	--	155.9	1198	7.68
Glycerol	--	291.4	4416	15.2
Methanol	--	175.4	759	4.33

( ) indicates value has uncertain reliability.
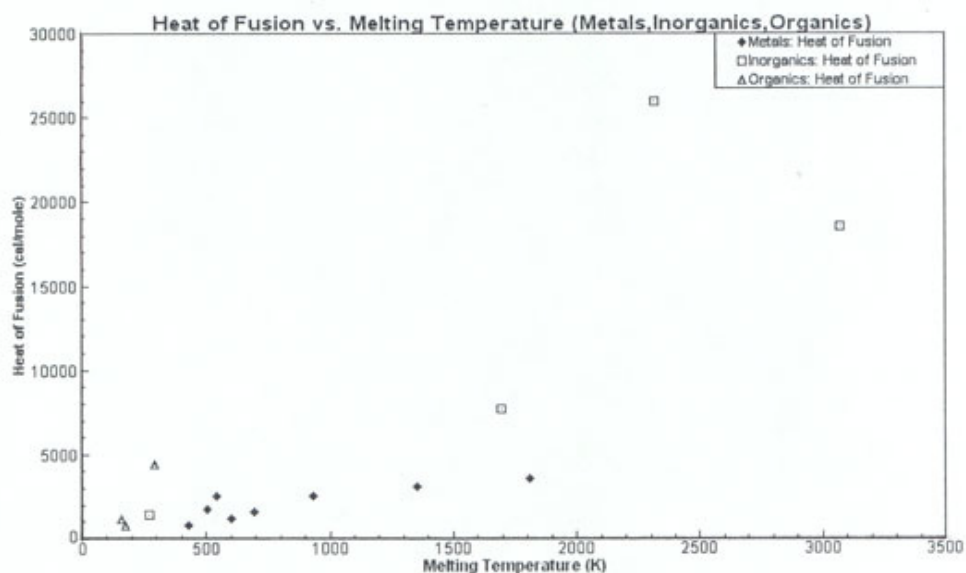
Figure 6. Latent heat of fusion versus melting temperature for various materials.

4. The current experiment relates to several previous years' NEW papers [22-25] on binary phase diagrams for metal systems. Of these papers, two [24,25] involve actually constructing the equilibrium diagram from cooling curve data.

5. The voltage-temperature conversion factor is provided by the digital thermometer's manufacturer (Omega Engineering, Inc.).

6. The highest concentration ethanol solution studied is dictated by the lowest temperature achievable with the immersion cooler. In the currelit work, this was determined to be -28.6° C.

7. Here, additional experimental results obtained by the instructor and/or students from past years are used together with results from the current work to prepare a partial phase diagram. This is suggested because minimal educational value is derived from students obtaining additional warming curves.

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SOURCES OF SUPPLIES: 95 vol% ethanol can be obtained at a variety of chemical supply houses.

Wayne L. Elban

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USE OF CAMBRIDGE ENGINEERING SELECTOR IN A MATERIALS/MANUFACTURING COURSE
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Use of Cambridge Engineering Selector in a Materials/Manufacturing Course

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Abstract

During the 1998-1999 academic year, Mechanical Engineering at Texas A&M University decided to combine a materials course that included a laboratory and a manufacturing course that contained a laboratory. As part of this activity, we decided to increase the design activity and material selection within the new course. Starting in fall 2002, we made a copy of a materials selection program, CES-4™ (Granta Design Limited) available to each student taking the course. A number of activities were devised to help the students become familiar with the program. The culminating activity was for each laboratory group to design a children's playground. They were to select the materials and the manufacturing processes for a playground that could handle 20 to 40 children from the ages of 2 or 3 to about 12 to 13 years old at one time. The Parks and Recreation Departments of both communities wanted the equipment to last 20 to 25 years with minimum maintenance. The application of the CES-4™ program to the design will be discussed and examples will be shown.

Keywords:

Materials, materials selection, manufacturing, design

Prerequisite Knowledge:

Introductory materials course, engineering math, mechanics of materials

Objectives:

To develop the materials selection and design capability of junior mechanical engineering students.

Equipment and Materials:

CES-4 Software and suitable computer, mutiple disk copying machine

Introduction

Selection of materials and manufacturing processes are important concepts that faculty would like engineering students to be able to understand and use. There have been a variety of methods developed to help do this. ASM International has published books that help.[1, 2, & 3] Several textbooks have collected data on materials and their properties.[4 & 5] One of the most complete is Callister's text, <u>Material Science and Engineering</u> where the author has collected a range of data on approximately 70 materials.[6] The CD that comes with the text is searchable. M. F. Ashby developed a series of selection charts some years ago where he demonstrated that a wide range of materials properties could be collected and plotted on the same abscissa and ordinate.[7] Using the idea of these Ashby charts, a company Granta Design, Ltd., has developed a software package, Cambridge Engineering Selector (CES), which includes a wide range of data on materials, manufacturing processes, and shapes for approximately 3000 engineering materials. The program is very powerful, and is potentially useful for students in mechanical engineering.

The objective of this paper will be to describe the use of the CES-4 software in a junior level materials and manufacturing course. During the course, students' practice using the software through several homework assignments and team projects. These will be discussed.

Procedure:

The Company, Granta Design, Ltd., has an educational arrangement that makes it very reasonable for a university or college to obtain access to the software for their students' use. Mechanical Engineering Texas A&M University purchased a site license for 250 students, and made enough copies so that each student in MEEN 360 received an individual copy that could be installed on their personal computer. The software has an internal clock that does not allow the program to run after one year from date of installation. The CES-4 package has an exceptional collection of data on each of the materials listed in the program. See Table 1 for an example of the properties available for cartridge brass (deep drawing) where more than 30 properties are listed. The units may be set to any of several different systems that are available.

Table 1. Example of data available from CES-4.[8]

Brass: deep-drawing/cartridge brass, CuZn28, soft (wrought) (UNS C25600)
General
Tradenames

SPRING WIRE BRASS, American manufacture (USA); HELMET METAL, English manufacture (UK); NEUSTADT, German manufacture (Germany); ANGSBURG, Manufacturer unknown (); LYON'S GOLD, English manufacture (UK); COMMON TOMBAC, French manufacture (France); PRYM 225, Prymetall GmbH & Co. KG (GERMANY); WIELAND-M28, Wieland-Werke AG (GERMANY); ;

Designation

Copper Alloy: CuZn28 (UNS C25600)

Density		0.3063	-	0.3125	lb/in^3
Energy Content		1.083e+004	-	1.3e+004	kcal/lb
Price		0.8736	-	0.9199	USD/lb
Recycle Fraction	*	0.4	-	0.5	

Composition
Composition (Summary)

Cu/28Zn

Base	Cu (Copper)	
Cu (Copper)	72	%
Zn (Zinc)	28	%

Mechanical

Bulk Modulus	*	17.07	-	18.01	10^6 psi
Compressive Strength		15.95	-	17.4	ksi
Elongation		50	-	52	%
Elastic Limit		15.95	-	17.4	ksi
Endurance Limit	*	21.9	-	22.63	ksi
Fracture Toughness	*	64.07	-	66.52	ksi.in^1/2
Hardness - Vickers		63	-	72	HV
Loss Coefficient	*	2.78e-004	-	3.31e-004	
Modulus of Rupture		15.95	-	17.4	ksi
Poisson's Ratio		0.34	-	0.35	
Shape Factor		30			
Shear Modulus	*	5.845	-	6.179	10^6 psi
Tensile Strength		45.69	-	47.86	ksi
Young's Modulus		15.81	-	16.68	10^6 psi

Thermal

Maximum Service Temperature		846	-	864	°R
Melting Point		2214	-	2241	°R
Minimum Service Temperature		0			°R
Specific Heat	*	0.09066	-	0.09114	BTU/lb.F
Thermal Conductivity		69.33	-	72.8	BTU.ft/h.ft^2.F
Thermal Expansion		9.944	-	10.61	μstrain/°F

Electrical

Resistivity   5.89   -   6.46   µohm.cm

Optical

Transparency   Opaque

Environmental Resistance

Flammability   Very Good
Fresh Water   Very Good
Organic Solvents   Very Good
Oxidation at 500C   Average
Sea Water   Very Good
Strong Acid   Poor
Strong Alkalis   Very Good
UV   Very Good
Wear   Very Good
Weak Acid   Good
Weak Alkalis   Very Good

Notes

Typical Uses

Deep-drawn items including cartridge cases & heat exhangers (fresh clean water); cold-headed parts; hardware.

Other Notes

(s)=soft; (1/2 h)=half hard; (h)=hard; (xh)=extra hard; (hr) = hot rolled; (w)=soln heat-trtd; (wh)=soln heat-trtd & work hdnd; (wp)=soln heat-trtd & precip hdnd; (whp)=precip hdnd after cold-wkng; (wph)=work hdnd after precip hdng.

Reference Sources

Data compiled from multiple sources. See links to the References table.

Links

Reference
Shape
Structural Sections
Supplier
ProcessUniverse

Assignment 1

The first assignment, shown below, asked the students to select the maximum and minimum properties for a number of attributes. For the specific modulus and strength, the students had to use the software included in CES-4 to divide that particular property by the material's density. Additionally, they were to plot a figure using the software. Interestingly, several students found a much more efficient method of doing it than I had.

_____

MEEN 360, F2002
Cambridge Engineering Selector
Pair or Individual Activity, Due: _____
Names _____ & _____

1. Use the Cambridge Engineering Selector to find information on the materials that satisfy the following attributes. There should be a set of answers for each attribute; they are independent of each other. Attributes Endurance Limit, Price, Seawater, Specific Modulus, and Specific Strength will have only two categories maximum and minimum (no intermediate category).

Attribute	Maximum	Minimum
Density		
Melting Point		
Fracture Toughness		
Thermal Expansion		
Endurance Limit		
Maximum Service Temperature		

Price		
Seawater[1]	Excellent	Very Poor
Specific Modulus		
Specific Strength		

2. Tensile strength, σ_{TS}, vs K_{1C} Show the entire plot. From the plot show all materials with $\sigma_{TS} > 150,000$ psi with a $K_{1C} > 35$ ksi in$^{1/2}$.

The activity may be done in pairs to make it easier to work through the questions and help each other. You certainly may work individually if you want to. The program contains a process and shape selector in addition to the materials selector. We will use the manufacturing selection component next time.

Assignment 2

The second assignment, shown below, provided the students with several different scenarios, and they were to select the material or process or shape that best fit the particular requirements listed. This activity required them to use the process and shape universes in addition to the material universe.

MEEN 360
CES HW 2
Name(s) _____ & _____

Answer the following three material selection questions.
1. Select material(s) with these particular attributes:
   - a minimum elongation of 10%
   - a maximum service temperature of between 900 and 1025 R
   - very good oxidation resistance at 500 °C
   - a maximum cost of $5/lb

List number of materials
   - if for the same conditions as listed above, you want the maximum density to 0.28 lb/in^3, then which materials remain in the running?
2. Using the Process Universe and Surface Treatment, which process would be selected under the conditions listed below?
   - curve surface coverage, average
   - coating thickness normal, 1to 5 mils
   - component area, restricted
   - Processing temperature, minimum 600°R
   - Surface roughness, very smooth
   - Corrosion protection, aqueous, yes
   - Friction control, yes
3. Try Processing Universe- Shaping
   - hole diameter in 1000 mil
   - mass range, maximum 10 lb
   - section thickness, maximum 3000 mil
   - quality factor of 5
   - Tolerance, 10 mil maximum
   - Economic batch size, 2 lb max
   - Production rate, 0.001/s
   - Primary process characteristics, Yes
   - Secondary, No

---

[1] For this attribute include five materials that are excellent and 5 that are very poor in seawater.

Assignment 3

       This was the first of two semester projects, which they did using their laboratory groups. The use of CES was not required, but only suggested. As often is the case, those students who had a person in their group that was motivated to use the software did, those that did not chose not to.

MEEN 360, Fall 2002
PROJECT # 1
Due 18Oct02

       Each laboratory group will select a small appliance, for example- coffee pot, hair dryer, iron, etc. (there should be at least 6 parts in the appliance), and answer the following questions concerning the item your group selected.

1. Take the appliance apart, and describe how you did it. Be sure to include sketches of all the parts and the assembly (an exploded assembly).

2. Identify the materials that make up the appliance. (CES may be helpful)

3. Determine the functional requirements for each part. (See design flow chart handed out with our syllabus.)

4. Describe the manufacturing process(es) that were used to make the individual parts.

5. Reassemble the entire appliance. Describe the procedure.

6. What recommendations would you make to improve the appliance with regard to ease of operation, ergonomics, appearance, safety, etc.?

Reporting Procedure:
       Each group will turn one typed report with the above information included. The drawings may be hand drawn or computer generated, and should demonstrate good engineering practice. (ENGR 111/112)

Assignment 4

       The fourth assignment, given below, was the second and final project for the semester. I gave the assignment out later in the semester, and so the students' complaint was that there was insufficient time to do it properly. They had a valid complaint, and next time I will give the project out earlier. However, there was a range in the quality of the final product. Several were simply terrific, while others appeared to have been tossed together while meeting at the kitchen table the night before. Generally speaking, I was pleased with the results, and most of the groups made a serious effort to use the CES-4 software, and I think it really enhanced their report and analysis. The grade distribution is shown in Table 2, and at least from the grades the distribution in quality may be observed.

MEEN 360
Project 2, Fall 2002
Lab Group Project

Problem Statement:

You have been asked to select materials and manufacturing processes for the components that make up a children's playground. It is to be built in an area similar (climate wise) to Bryan/College Station. The playground should be able to handle upwards of 20 to 40 children from the ages of 2 or 3 to about 12 to 13 years old at one time. The Parks and Recreation Departments of both communities would like the equipment to last 20 to 25 years with a minimum of maintenance.

1. Use the design format that we introduced this fall.
2. Select the materials and manufacturing process for the equipment.
3. For one of the particular playground items (slide, tube, etc.) perform a thorough design.
    a. Loads, fatigue life, safety, corrosion, detailed manufacturing steps, assembly procedures, etc.
4. If you would like to speak directly with a park's person, the director of the Bryan Parks and Recreation Department, David Schmitz, has agreed to be a contact person, Ph. No. 209-5201, e-mail: dschmitz@ci.bryan.tx.us. In fact, he is a certified playground specialist. In addition, College Station Parks and Recreation also has a person who is willing to be a point of contact his name is Pete Vanecek, Ph. No. 764-3412, e-mail: pvanecek@ci.college-station.tx.us.
5. There are a number of attractive playgrounds in the two towns: Tanglewood, Central Park, Villa West, Astin, Bee Creek, etc.

Due Date: 4:00 pm, last day of classes 9/10 Dec. 02

Assignment 5

This assignment was given as a take home portion of the final examination. It required the students to use basic mechanics of materials to help find the property that needed to be minimized to help in the final selection. I selected these two from the accompanying text, not realizing that they were on the CES website. Students that found the website had an easy time

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MEEN 360
Final Exam- Take Home Component
Name _____

Students are to work the exam by themselves. You may discuss ideas with classmates, but you may not copy someone else's work. The exam will be turned in at the beginning of the final exam, Monday 16 Dec. 02 at 8 am.

1. Credit for inventing the rowed boat seems to belong to the Egyptians. Boats with oars appear in carved relief on monuments built in Egypt between 3300 and 3000 BCE (Before the Common Era), Boats, before steam power, could be propelled by poling, by sail, and by oar. Oars gave more control that the other two, and their military 0potential was well understood by the Romans, the Vikings, American Indians, and Venetians. Select candidate materials for an oar. Two other constraints are: toughness needs $> 1kJ/m^2$ and cost needs $< \$100/kg$.

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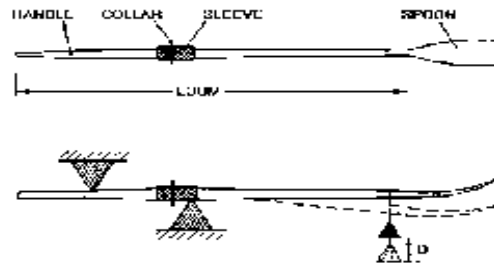
Figure 2.: Oars are designed on stiffness, measured in the way shown in the lower figure; and they must be light.

MEEN 360
Final Exam- Take Home Component
Name _____

Students are to work the exam by themselves. You may discuss ideas with classmates, but you may not copy someone else's work. The exam will be turned in at the beginning of the final exam, Wednesday 18 Dec. 02 at 8 am.

1. Luigi Tavolino, furniture designer, conceives of a lightweight table of daring simplicity: a flat sheet of toughened glass supported on slender, unbraced, cylindrical legs, see Figure 4.1. The legs must be solid (to make them thin) and as light as possible (to make the table easier to move). They must support the tabletop and whatever is place upon it without buckling. What materials would you recommend?
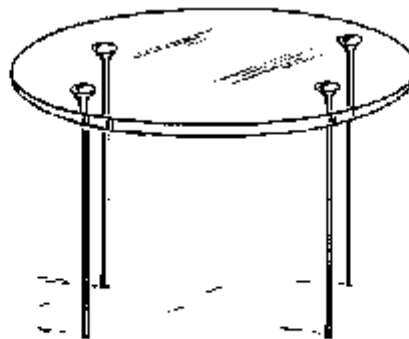
Figure 4.1 A light-weight table with slender cylindrical legs. Lightness and slenderness are independent design objectives, both constrained by the requirement that the legs must not buckle when the table is loaded.

The legs need to have adequate toughness. A useful rule of thumb is that

$$G_c = (K_{1C})^2/E \geq 1 \text{ kJ/m}^2$$

for adequate toughness.

while those who tried it on their own struggled. I was moderately satisfied with the results. The grades for two projects and the take home exam are given in Table 2. There were about 90 students in the class. I had two sections: one MWF and the other TTh, one of the above was used in each section.

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Table 2. Grades for the two projects and the take home final.

Grades	Project 1	Project 2	Take Home Final
Average	83.9	80	77.3
Standard Deviation	11.5	16.1	16
Maximum	95	100	100
Minimum	66	53	25

Comments:

The CES-4 materials and processes selection software was used in a junior level materials and manufacturing processes course. The results were satisfactory; students who took the next course which required the use of the software felt as if they had been helped by the use of it in the class describe in this paper. Anecdotally, faculty in follow on design courses reported on students using the software in their class. From my standpoint, I appreciated the tremendous amount of information that is available on a wide range of materials. Several of the assignments need to be made more rigorous so that the students are encouraged to use the process and shape universes more and at a higher level.

Acknowledgements:

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POLYCRYSTALLINE BISMUTH FILTERS FOR THE FILTER ANALYZER NEUTRON SPECTROMETER (FANS)

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Polycrystalline Bismuth Filters for the Filter Analyzer Neutron Spectrometer (FANS)

National Educators' Workshop
Oct 19-22, 2003
NASA Langley

Key Words: powder metallurgy, cold pressing, hot pressing, Carver hydraulic press, neutron beam interaction, recrystallization, infrared spectroscopy, morphology, dislocation density, FANS, SANS

Prerequisite Knowledge: physics (optics), powder metallurgy, knowledge of electronics

This planned cooperation stems from a research project that aims to fill a requirement for polycrystalline Bismuth filters for application in the Filter Analyzer Neutron Spectrometer (FANS) that is currently installed at BT4 in the NCNR.

The size and shape of the desired filters is a straightforward geometric matter, best described by a truncated pyramid with a 2 fold axis (unlike Cheops, which has a 4-fold axis and is not truncated). There is no final design available, but the path to that, however time consuming, is straightforward.

The currently adopted fabrication method is cold pressing of granular Bismuth, which considering the melting temperature of Bismuth -- in metallurgical terms -- is probably close to a "hot" process, thus opening up the possibility that recrystallization takes place at room temperature.

The base materials utilized: 200 mesh powder, 100 mesh powder, and water quenched maggot shaped/sized granules. All base metals are specified to be 99.9% bismuth or better.

For characterization (using neutrons to measure the material-characteristic absorption edge) purposes, a laboratory pressing die was employed (like the ones used for infrared spectroscopy specimens) and loaded in a 20 ton Carver hydraulic press. Creating consistently sound samples regardless of base material used have been quite successful. All trials thus far have taken place at room temperature. We reach a density of about 99.5% of theoretical in cylindrical samples of 25 mm diameter and 25 mm high.

The neutron beam interaction appears to be a function of the morphology of the base metal, which suggests that the material is a compound forging. Other hypotheses include the presence of excess oxides, which is supported by better filter performance with decreasing mesh size of the base material (oxides greatly disturb the filter efficacy: more surface more oxides). In

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addition porosity and final grain size might play a role, as well as excessive dislocation density. This would be supported by the same observation.

The specifications for final grain size are hard to pin down and are limited to desired filter performance, the optimum of which is hard to quantify and a somewhat subjective matter. It is believed that anywhere between 10 and 100 microns would yield an acceptable filter material, provided the material is otherwise free of contaminants such as oxygen (in oxides) and has no porosity or excessive dislocation density. Our powder metallurgy approach probably eliminates texture altogether.

Our knowledge of the metallurgy of Bismuth at this point is limited to its apparent forgeablility. This is somewhat unexpected, but certainly most welcome given the final goal of this endeavor. Bismuth is a poor heat conductor and has a non-traditional crystal structure.

Several ways to characterize these samples are being further contemplated using a metallurgical approach starting from a premise that all base metals be deployed and parametrized in the same way. To that end we would like to gently anneal the samples at several temperatures and find ways to chemically reduce, or otherwise remove any oxides. The former is a matter of temperature selection, something like a selection of 5 different temperatures ($0.55T_m$, $0.65T_m$, $0.75T_m$, $0.85T_m$ and $0.95T_m$, T_m is the Bismuth melting temperature in Kelvin). The latter would be a complex process variable: pretreatment of the base metal, either by some gas chemistry, or a strong reducer applied in some other way. Temperature of these processes must be low, otherwise our base metal will start to sinter (although it would be interesting to find out at what temperature and physical condition this would actually happen).

FANS - The Design, phase I

Beam Stop

Detectors

Shielding

Be Filter

Graphite Filter

Bi Filter

Sample

Collimator

Be Filter

Monochromator

BT-4

Shielding

FANS - The Design, phase-II

Beam Stop

Detectors

Shielding

Be Filter

Sample

Graphite Filter

Collimator

Be Filter

Bi Filter

Monochromator

BT-4

Shielding

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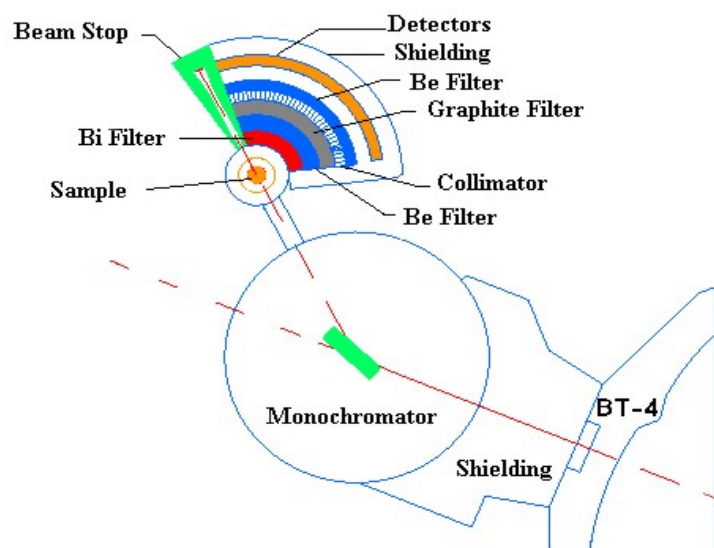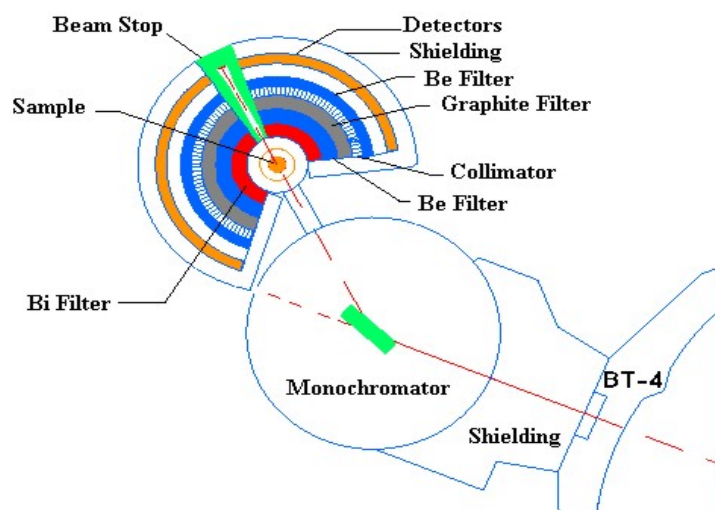
The side view cross-section through the filter-detector assembly shows blocks of polycrystalline beryllium and graphite which diffract all neutrons with energies above 1.8 meV, as well as the removable bismuth filter.
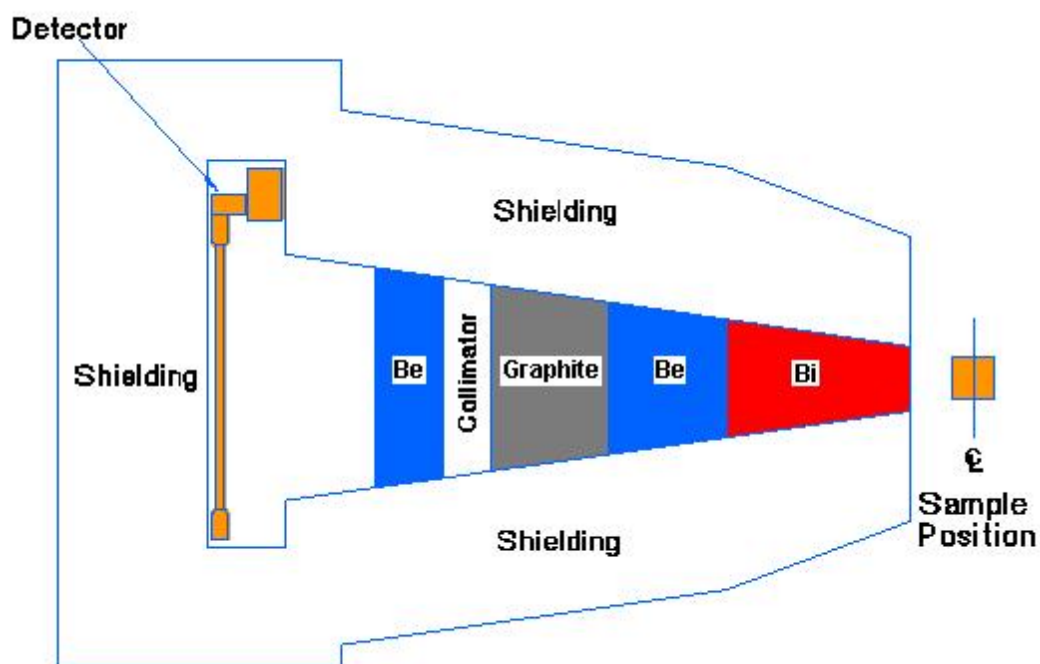
MECHANICAL BEHAVIOR OF COMPOSITE MATERIALS: THE ROLE OF FIBER TYPE FIBER CONTENT AND VOID CONTENT
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Behavior of Composites

Effects of Fiber Type and Content
or

Can We Break Something Today?

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Textbook Composites

(from Ashby, Material Selection in Mechanical Design)

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Textbook Composites

(from Ashby, Material Selection in Mechanical Design)

Textbook Composites

(from Ashby, Material Selection in Mechanical Design)

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Textbook Composites

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Textbook Composites

Polaris A2, SLBM (1962)

Polaris A3, SLBM (1964)

Textbook Composites

F-111: Variable swept wing multipurpose tactical
Bomber capable of supersonic speeds (1964.)

Boron Doubler on F111
Wing Pivot
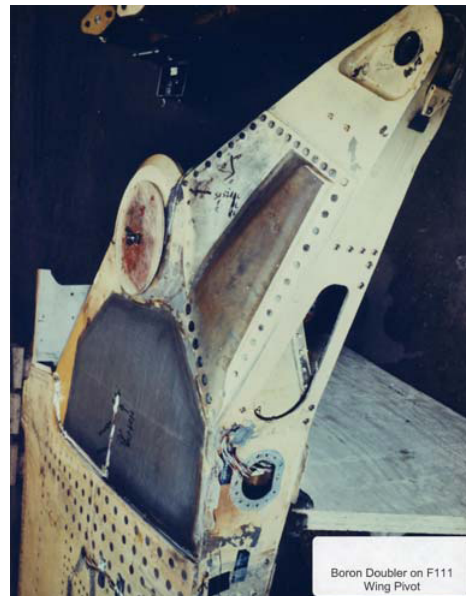
Textbook Composites

Enough already, can we break something today?

- Wet layup and vacuum bagging demo
- ASTM Standards database search
  — Tension testing
  — Compression testing
  — Shear testing
- Tension testing of glass-fiber/epoxy and carbon-fiber epoxy composites
  — Effect of fiber type
  — Effect of fiber orientation
  — Fiber dominated properties vs. matrix dominated properties
- ASTM Standards database search
  — Density determination
  — Fiber volume fraction determination
  — Void content measurement
- Determination of fiber volume fraction and void content
- Mechanical testing of vacuum bag cured composites

Wet layup and autoclave curing/vacuum bagging demo

- Learning objective: to expose the students to the basic techniques of composites manufacturing.
- Materials and equipment needed for this demonstration:
    — Unidirectional glass fabric (~9 oz/yd^2)
    — Unidirectional carbon fabric (~9 oz/yd^2)
    — Room temperature curing epoxy (West Systems 105/206 hardener)
    — Squeegees
    — Paintbrushes
    — Vacuum bag material (nylon film)
    — Release ply material
    — Breather cloth
    — Vacuum sealant tape
    — Vacuum pump, hose and probe to evacuate vacuum bag
    — Latex gloves
    — Autoclave (?)

Wet layup and autoclave curing/vacuum bagging demo

- Procedure: have each student try their hand at wetting out the two fabrics, let them experiment. Explain how to construct a vacuum bag and the purpose behind vacuum bag curing.

Composite Bagging for Cure

1	Bag Sealant	8	Perforated release film
2	Vacuum Fitting and assorted hardware	9	Nonperforated release film
3	Bagging Film	10	Peel ply
4	Open-weave breather mat	11	Laminate
5	Polyester tape(wide)	12	1581- style glass breather manifold
6	Polyester tape (narrow)	13	1581-style glass bleeder ply
7	Caul Sheet	14	Stacked silicon edge dam
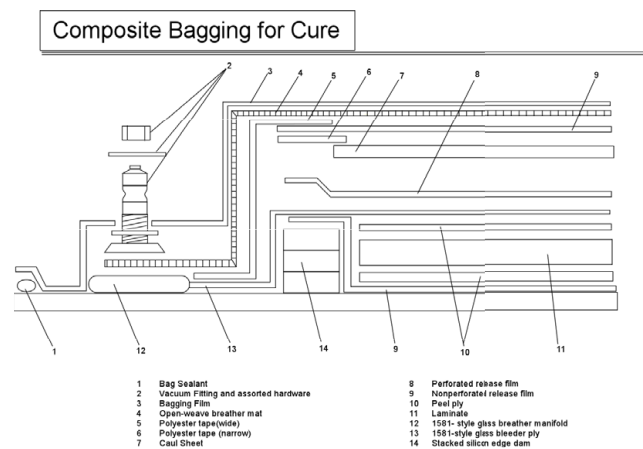
Wet layup and autoclave curing/vacuum bagging demo

Julia Child Formula —*when the students are not present*

fabricate four panels

1)   Six plies glass-fabric/epoxy vacuum bag cure only
2)   Six plies glass-fabric/epoxy vacuum bag + autoclave pressure = 75 psi
3)   Six plies carbon-fabric/epoxy vacuum bag cure only
4)   Six plies carbon-fabric/epoxy vacuum bag + autoclave pressure = 75 psi

These panels will be used in all subsequent phases of this experiment.

ASTM Standards database search

- Learning objective: to expose the students to the ASTM standards database and to familiarize them with some of the test techniques unique to composite materials testing.
- Procedure: have the students perform a keyword search to find the standards pertaining to tension, compression and shear testing of composites. Have the students tabulate their search results and then have them write a brief summary of each test technique including a brief description of the specimen geometry used for each and any special instrumentation requirements that might apply.

ASTM Standards database search

- Tension testing:
  - ASTM Standard D3039-00, *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.*
- Compression testing:
  - ASTM Standard D3410-95, *Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading.*
  - ASTM Standard D695-96, *Compressive Properties of Rigid Plastics.*
  - ASTM Standard D5467-97, *Compressive Properties of Unidirectional Polymer Matrix Composites Using a Sandwich Beam.*
  - ASTM Standard D6641-01, *Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture.*

ASTM Standards database search

- Shear testing:
  - ASTM Standard D5379-98, *Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method.*
  - ASTM Standard D4255-01, *Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method.*
  - ASTM Standard D3518-94, *Practice for In-Plane Shear Stress-Strain Response of Unidirectional Polymer Matrix Composite Materials by Tensile Test of +/-45° Laminate.*
  - ASTM Standard D2344-01, *Test Method for Short Beam Strength of Polymer Matrix Composite Materials and their Laminates by Short-Beam Method.*

Tension testing
(*the effects of fiber type and orientation*)

- Learning objective: to demonstrate the effects of fiber type and orientation on the mechanical response of composites.
- Materials and equipment needed for this experiment:
  - Tensile specimens of glass/epoxy and carbon/epoxy prepared according to ASTM D3039
  - Flat tensile grips either wedge action or hydraulic
  - Electromechanical or servohydraulic test machine of adequate capacity (~30 kips)
  - Digital data acquisition for load, stroke, and strain.
  - Safety shield to contain fragments.

Tension testing
(*the effects of fiber type and orientation*)

Test Specimen Preparation

A.) 0° tension specimens: 10" x 0.5" with 2.0" long bonded end tabs[*]

B.) 30° tension specimens: 9" x 1.0" with 2.0" long bonded end tabs

C.) 90° tension specimens: 10" x 1.0" with 2.0" long bonded tabs

D.) SBS specimens (0° and 90°): 1.5" x 0.25"

E.) 0° compression specimens: 5.5" (+0.1/-0.0) x 0.5" with 2.5" long bonded tabs (it is important to maintain 0.5" gage length.)

F.) Interlaminar shear strength: 3.13" (+0.1/-0.0) x 0.5"

• - The end tabs are to be 0.125" thick G-10 material. All end tabs are to be ground to point with a taper angle of 30°. It is suggested that the end tabs be bonded to the laminate in large pieces prior to sectioning. The gage section in all cases should be free of tabbing adhesive. For (E) it is important that the tab tips be exactly 0.5" apart, square and parallel with no tabbing adhesive in the gage section.

When sectioning the panel, care should be taken such that all specimen edges are square and parallel.

General Laminate

0 degree direction
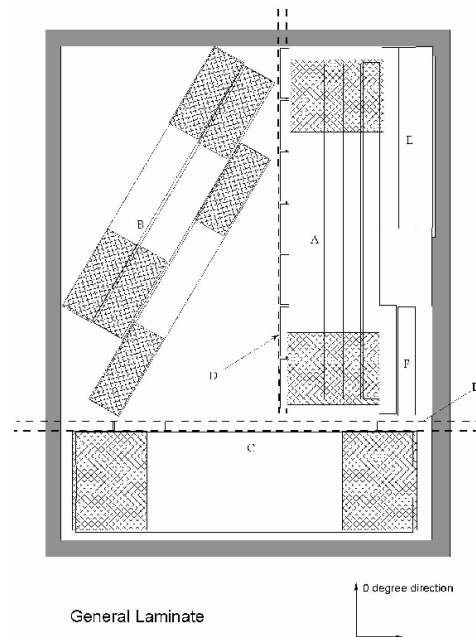
Tension testing
(*the effects of fiber type and orientation*)

- Procedure: break test coupons of glass/epoxy and carbon/epoxy composite from each of three different orientations. For each test record at least the peak load and if possible collect load-elongation data for each test. Provide the test data to the students in electronic format and have the students plot stress-strain diagrams for each test. Have them compute the elastic modulus for each test and then tabulate (or plot) ultimate tensile strength and elastic modulus for all tests.

Tension testing

(*the effects of fiber type and orientation*)

- Results: sample test data.

Material	Average tensile strength
1020 steel – hot rolled	340 MPa
6061-T6 Aluminum	300 MPa
Carbon/epoxy (75 psi) - L	680 MPa
Carbon/epoxy (75 psi) - T	35 MPa
Carbon/epoxy (0 psi) - L	420 MPa
Carbon/epoxy (0 psi) - T	26 MPa
Glass/epoxy (75 psi) - L	550 MPa
Glass/epoxy (75 psi) - T	32 MPa
Glass/epoxy (0 psi) - L	370 MPa
Glass/epoxy (0 psi) - T	25 MPa

ASTM Standards database search

- Learning objective: to expose the students to the ASTM standards database and to familiarize them with some of the test techniques used in the physical characterization of composites.

- Procedure: have the students perform a keyword search to find the standards pertaining to density determination, fiber volume fraction measurement, and void content determination. Have the students tabulate their search results and then have them write a brief summary of each test technique including a brief description of the procedure. *Have them gather in small groups and plan this experiment.*

ASTM Standards database search

- Writing Across the Curriculum

- Einstein – "you don't really understand something until you can explain it to your mother."

ASTM Standards database search

- Density determination:
  - ASTM Standard D1505-98, *Test Method for Density of Plastics by the Density-Gradient Technique.*
- Fiber volume fraction measurement:
  - ASTM Standard D3171-99, *Test Method for Constituent Content of Composite Materials.*
  - ASTM Standard D2584-94, *Test Method for Ignition Loss of Cured Reinforced Resins.*
- Void content determination:
  - ASTM Standard D2734-94, *Test Method for Void Content of Reinforced Plastics.*

Density determination

- Learning objective:

- Materials and equipment needed for this experiment:
  - 5 g of composite material to be measured
  - Density determination cup
  - Distilled water
  - Analytical balance (+/-0.0001 g)

Density determination

- Procedure: remove 1" x 1" test samples from the scrap region of the panels fabricated in the wet layup demo. Give each pair of students a density determination cup and one sample of both glass/epoxy composite carbon/epoxy composite.

Density determination

- Procedure: (cont.)

Mass the density determination
cup with water (M_c)
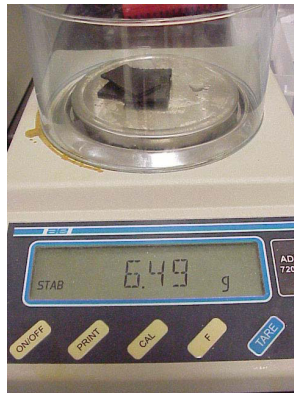
Mass the composite sample (M_s)
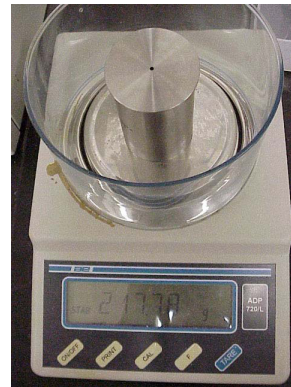
Mass the density determination
cup with sample in water (M_T)

Density determination

- Procedure: (cont.)
  - Compute the composite density using Archimedes principle:

$$\rho_c = \frac{M_s}{M_s - (M_T - M_c)}$$

  - <u>No need for repetitions</u>, instead tabulate class data for each panel and compute average density and standard deviation for each panel.

  - Good time to have students measure panel thickness also. . .

Density determination

- Results: sample results
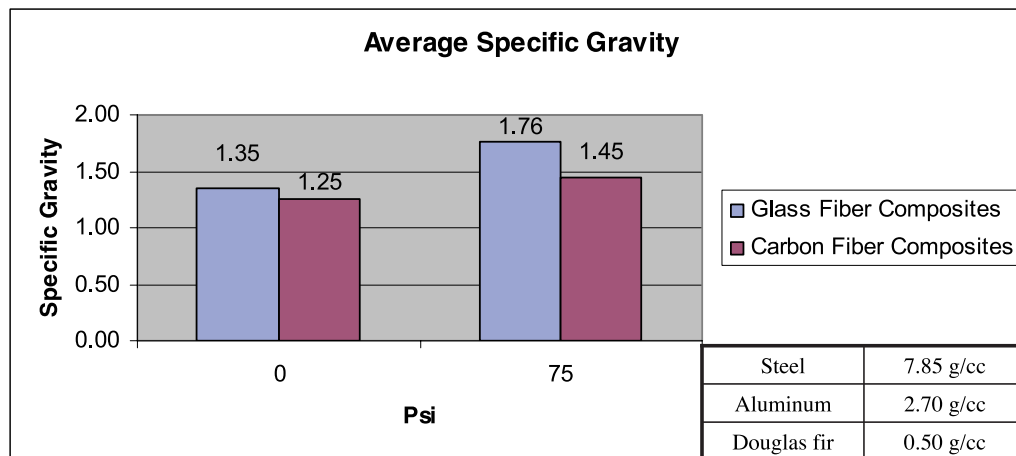
Optional – Specific strength

- Compute specific tensile strength for all four composite panels and compare with that of 1020 steel, 6061-T6 Al, and Douglas fir.

Fiber and void content determination

- Learning objective: to give students an understanding of fiber volume fraction by measuring it.
- Materials and equipment needed for this experiment:
  - <u>Chemical Matrix Digestion Method</u>
    - Fume hood
    - Filter flask
    - Buchner funnel with fritted funnel (medium)
    - 400 ml beaker
    - Nitric acid
    - Hotplate
    - Dessicator
    - Analytical balance
    - Rubber gloves and safety goggles

Fiber and void content determination

- Procedure - Carbon fiber/epoxy composite:

Mass Sample

Dissolve Epoxy in Nitric Acid

Fiber and void content determination

- Procedure - Carbon fiber/epoxy composite:

Weigh Funnel
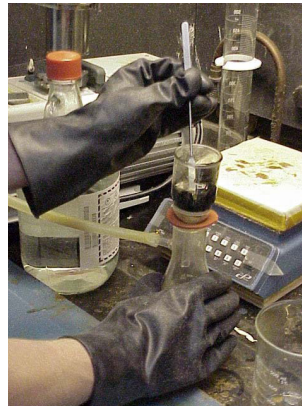
Filter fiber residue

Cooling sample in
dessicator

Massing fiber residue

Fiber and void content determination

- Materials and equipment needed for this experiment:
  - <u>Resin Ignition Loss Method</u>
    - Fume hood
    - Ceramic crucible
    - Bunsen burner or propane torch
    - Muffle furnace
    - Dessicator
    - Analytical balance
    - Rubber gloves and safety goggles

Fiber and void content determination

- **Procedure - Glass fiber/epoxy composite:**
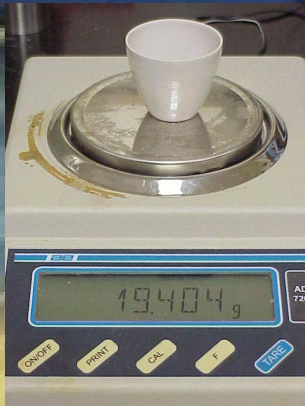
Mass Crucible

Fiber and void content determination

- Procedure - Glass fiber/epoxy composite:

Ash Samples in Muffle Furnace
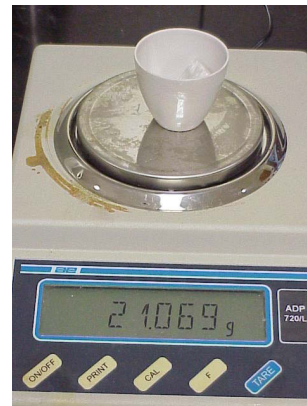
Mass crucible and sample

after resign ignition

Fiber and void content determination

- Calculations:

$$V_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f}$$

$$V_v = \frac{\rho_t - \rho_c}{\rho_t}$$

$$\rho_t = \frac{M_s}{\dfrac{M_m}{\rho_m} + \dfrac{M_f}{\rho_f}}$$

Fiber and void content determination
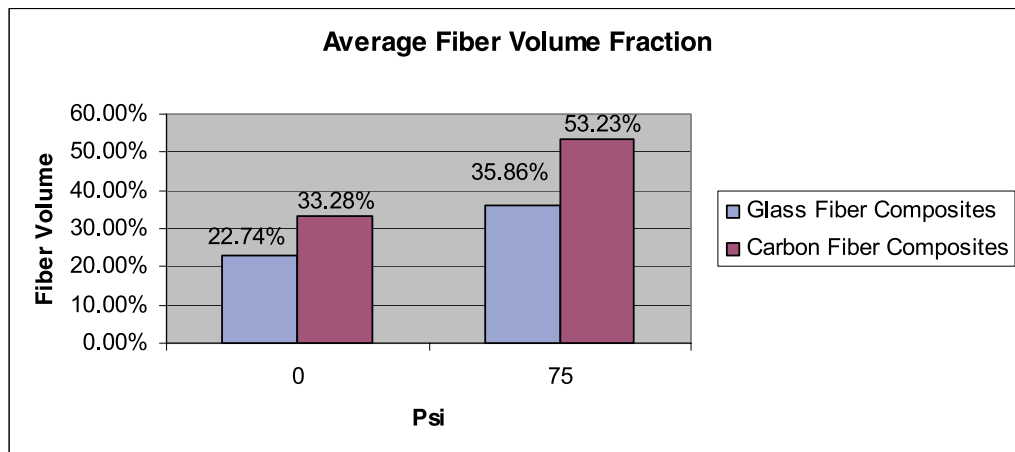
- Results:

Fiber and void content determination

- Results:
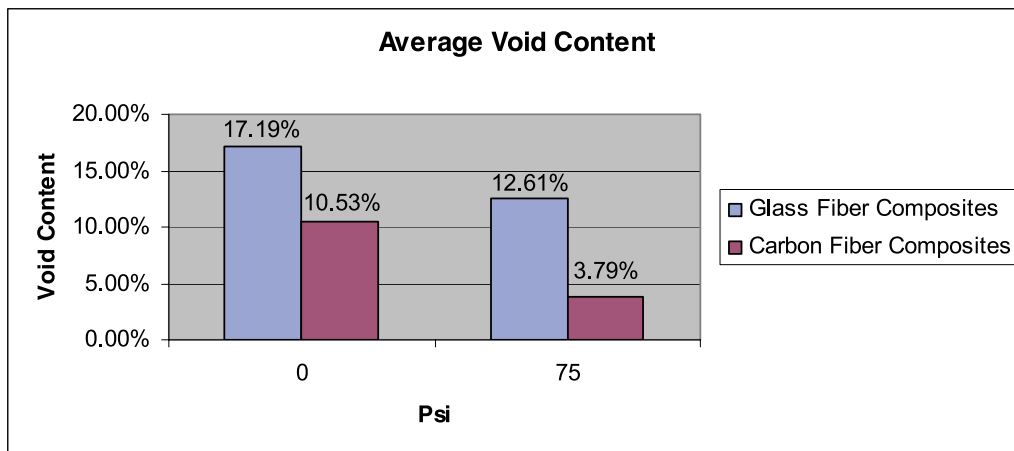
Summary
(Effects of Fiber Type and Content)

Material	Fiber Volume Fraction	Average tensile strength
Carbon/epoxy (75 psi) - L	53%	680 MPa
Carbon/epoxy (75 psi) - T	53%	35 MPa
Carbon/epoxy (0 psi) - L	33%	420 MPa
Carbon/epoxy (0 psi) - T	33%	26 MPa
Glass/epoxy (75 psi) - L	36%	550 MPa
Glass/epoxy (75 psi) - T	36%	32 MPa
Glass/epoxy (0 psi) - L	23%	370 MPa
Glass/epoxy (0 psi) - T	23%	25 MPa

Optional – Benefits of vacuum bagging

- Vacuum bag produces 1 ton/ft^2 pressure which yields composites of lower density and higher fiber volume fraction along with lower void content and improved mechanical behavior.

Acknowledgements

- Ross Aylor, Senior at Southern High School in Harwood, MD → SEAP Program
- Bill Beaver, Technical Support Division

CRYSTALS AND X-RAYS: AN OPTICAL ANALOG
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Crystals and X-rays: an optical analog

National Educators' Workshop
October 2003

Maureen M. Julian
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Keywords: X-rays, Bragg's Law, teaching x-ray crystallography, history of x-rays

Prerequisite Knowledge: general chemistry or physics

Objective: To demonstrate Bragg's Law optically and dramatically within an historic context.

Equipment and Materials: Plane mirror, mirror ball, flashlight, x-ray photographs

Introduction:

Because of the subtleties of X-ray photographs, experimental X-ray diffraction is a difficult topic to introduce in an undergraduate curriculum. I have developed a dramatic lecture hall demonstration on crystals and X-rays using a mirror ball typically found in roller skating rinks. In a darkened lecture hall, a single spotlight is focused on the stationary mirror ball and the walls of the hall are immediately covered with a display of light spots (1).

In 1912 Max Laue (2) theorized that the wavelength s of X-rays might be just about the same as the distances between atoms in crystals. If this were the case, then X-rays would be diffracted or bent by crystals. The first x-ray diffraction pattern was recorded from a beautiful blue crystal of copper sulfate pentahydrate.

Scientists strove to interpret the relationship between the pattern of spots, which appeared on the film, and the atoms, which make up the crystal. William H. Bragg, at the University of Leeds in England, visualized corpuscular X-ray tunneling down the many open avenues in the crystal. On July 21, 1912, Bragg wrote to the mathematical physicist Sir Arthur Schuster: "I wonder whether the rays producing the side [diffracted] spots are really "rays" proceeding in straight line from some point in the crystal (say where the X-ray impinges or emerges), or are they sections of some loci by the photographic plate. It all seems most mysterious!" (3).

During that summer at Leeds, Bragg had many discussions about the puzzles of X-ray diffraction with his son, William Lawrence Bragg, who was home on vacation from Cambridge University. When young Bragg returned to his studies he set a crystal of mica in the path of the X-ray beam. First, he noticed that the shape of the spot became flattened as the angle of the crystal about its axis increased. This increase contradicted the corpuscular theory and made him suspect that the crystal was behaving in a way analogous to the optical reflection of rays.
Furthermore, as the crystal was rotated though an angle, the diffracted spot moved through twice that angle. He then postulated that the layers of atoms within the crystal were acting as mirror-like reflecting planes and so applied the optical diffraction equation for grating to X-rays. Thus, the famous Bragg equation $n\lambda = 2\,d\sin\theta$ was born. In 1915 only three years

after Max Laue's outstanding experiment, 24-year-old William Lawrence Bragg became the youngest recipient of the Nobel Prize when he received it jointly with his father.

Procedure:

Single Mirror

First in a darkened room a beam of light is directed at a small hand mirror to demonstrate that the shape of the reflected beam changes as the mirror is rotated. Then the mirror is held horizontally so the light spot is directly overhead. While the students follow the light spot, the mirror is slowly rotate so that the light spot moves to a position ninety degrees from the ceiling, for example on the wall directly ahead of them. Then their attention is directed to the mirror, which is at an angle of forty-five degrees to the horizon. This procedure is repeated several times so that the demonstration is clear that the reflection rotates twice as far as the single mirror causing the reflection.

Mirror Ball – single crystal demonstration.

Again with the room darkened, the cloth covering the mirror ball, which has been carefully positioned, is quickly removed and immediately a dramatic pattern appears on the ceiling and walls. In this optical analogue of crystals and X-rays, the mirror ball represents the crystal, the light spots on the ceiling and walls are the diffracted X-ray reflections, the wall becomes the film, and the room itself becomes the giant camera. The spotlight is 'monochromatic' because light is considered to be reflected at only a single angle. The "crystal" can be rotated showing that the pattern rotates with the crystal and the two effect mentioned under "single mirror" can be demonstrated. Although it is more confusing with the multiplicity of spots, a single spot can be selected and the change in shape can be seen as well as the fact that the spot will travel twice as far as the corresponding rotation of the mirror ball.

Mirror Ball- X-ray powder demonstration.

An important technique used in X-ray analysis is the powder method. A crystalline sample is ground into a powder, which is packed into a capillary tube. The powder contains many small crystals pointing in all directions. Many people have difficulty in understanding why the X-ray pattern produced by the powder crystals consists of lines. The mirror ball can give a convincing demonstration of how the lines are produced.

In a darkened room a single spotlight illuminates the mirror ball causing the corresponding light pattern on the wall. The mirror ball is rotated through a small angle. The new position represents the pattern produced by another "crystal" very close in orientation to the first crystal. Then the mirror ball is moved a tiny bit more. Again this position represents another crystal oriented close to but not precisely coinciding with its neighbor. The procedure is continued until class is convinced a random orientation can be represented by rotation of the mirror ball. For the high point of the demonstration the mirror ball is gently rotated until the points coalesce into parallel streaks and the powder pattern is displayed on the walls. The mirror ball does not have to go very fast; just a gentle twist with one's hand does it.

Comments:

An important difference between the model and the prototype is that in the real crystal the Bragg planes interpenetrate while in the model the little mirrors are glued to the outside of the sphere. However the mirror ball and the crystal reflect in only one position. In the crystal, this position is called the Bragg angle.

Another difference between the model and the prototype is that in the mirror ball crystal all planes reflect equally well resulting in light spots of equal brightness. In the real crystal all the planes are not equally populated with atoms. The intensity of the reflected X-ray beam depends on the electron density in the associated planes. Not all the crystal planes reflect X-rays equally, thus the intensities of the x-ray reflections vary tremendously and indeed are a function of the detailed crystal structure of the diffracting material.

Following the demonstrations with the mirror ball, actual x-ray photographs are shown illustrating the remarkable similarity between the patterns generated on the wall and the patterns produced by a real crystal diffracting X-rays.

I wish to thank all my students who have experience my mirror ball demonstration.

References:
1. M. Julian, J. Chem. Educ. **57**,10,1980, 737-8.
2. Ewald, P.P. 'Fifty years of X-ray diffraction," NVA Oosthoesk's Uitgeversmaatschappy, Utrecht, the Netherlands, 1962, pg. 31 f.
3. Caroe, G. M., "William Henry Bragg," Cambridge University Press, Cambridge, England, 1978, pg. 72.

Bibliography:

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DESIGN OF COMPLEX TECHNICAL EQUIPMENT BY DARWINIAN EVOLUTION
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Design of Complex Technical Equipment by Darwinian Evolution.

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Key Words: Analog circuit design, natural selection, evolution, student research project

Prerequisite Knowledge: Basic algorithm design, linear and analog circuit design, probability and statistics, error analysis.

Objectives:

1. For the student to learn to design a competent human-computer interface using a language such as Visual C^{++} or Visual Basic.

2. For the student to learn how to create a circuit "gene" and to use extant software such as pSpice to evaluate circuit performance.

3. For the student to learn how to develop and implement a "fitness" metric to determine circuit suitability.

4. To produce new designs as solutions to old problems.

5. To demonstrate that a computer system can design competent analog circuits without the need for human ingenuity vis-à-vis circuit design.

Equipment and Materials:

1. A high end desktop PC with Windows 2000 (or better).
2. A compiler for Visual C^{++} or Visual Basic 6.0 (or better).
3. A windows compatible version of pSpice (or equivalent type circuit analysis tool)
4. Access to an engineering reference library.

Introduction:

Design of equipment to perform certain functions and to meet given performance criteria is a fundamental activity for engineers. In the traditional approach to design, we select specific components and interconnect them in specific ways that we believe will achieve some desired

performance. We use various analysis techniques to evaluate the ability of our design to meet performance requirements. Using the results of analysis, we enter an iterative process of modifying and reevaluating the design. The success of this technique depends strongly on our individual experiences and imaginations.

Alternately, we could simply select a random number of component parts with randomly chosen performance characteristics. We could connect these components together quite randomly. When this device is tested against the required performance criteria, it would most likely fail miserably. However, if we create 10,000 such devices and test them all, some of them would meet the required performance criteria better than the others. We could use the best performing 10% of these devices as parents of the next generation. For each of the surviving 10%, generate 1,000 new circuits with randomly chosen additions, deletions, and component value changes. Evaluation of this second generation will likely produce some devices that perform better than any in the first generation.

This experiment aims to demonstrate that after 100's or 1,000's of generations, the best devices will meet any realistic set of performance requirements. No experience or imagination is necessary.

One of the investigators (GSK) became interested in strict-rule random systems in the early 1960's. The idea came from original research by an English biologist named Donald Michie in 1960. He described an experiment that involved a group of matchboxes displaying various tic-tac-toe board possibilities containing colored beads indicating the next move that could learn to play tic-tac-toe. The specific details as to how this would work is not important. What is important is that the experiment provided for a random selection of the next move, and then either rewarded or penalized each given matchbox in a game based on the outcome of the game. This is the fundamental theory underlying the idea of Darwinian natural selection. After playing a large number of games, and adjusting the colored beads within each matchbox according to the rules, the "machine" learned how to play a game of tic-tac-toe that would either win or end in a tie. This experiment demonstrated the fact that one could build a system that, with experience, could "learn" how to solve any given problem.

Much work has been done in the field of using "natural selection" to create systems that achieve technical goals. The largest volume centers around the design of computer algorithms to solve specific problems. There has been a fair amount of work using natural selection to generate purely digital logic hardware. Much of this has involved using natural selection to generate VHDL code. VHDL is a hardware description language. While there has been a lesser amount of work in designing purely analog circuitry, some of that work has been quite impressive. In one instance, a filter was created using natural selection that performs ideally. What is interesting is, that using conventional analysis of the circuit, no one knows how (why) the circuit works at all!

The fact that a strict-rule random system can generate useful circuits through natural selection is not in question. It has been demonstrated repeatedly. The principal subject of this research experiment is to examine the metric used in evaluating the "fitness" of a given circuit to meet the performance criteria. When designing analog circuitry in the traditional fashion, the designer

uses standard modeling tools to evaluate constituent components including Fourier analysis and superposition to predict overall circuit behavior. The designer plans the function of each component in the circuit, and analyzes its ability to meet that function. In our case, the completed circuit is simply presented to be tested for suitability. The test of such a circuit is rather like a sink-or-swim test. Without knowing the intended function of the constituent components, we need a test of the circuit as a whole that will give a number representing the circuits fitness. Determining what that number should represent is a daunting problem. Consider the case of having a band pass filter as the goal. If a spectrum analysis of the circuit is to be used to evaluate it, how can the circuit's response be represented as a single number. Consider the two cases below. Which actual response better conforms to the desired bandpass filter?
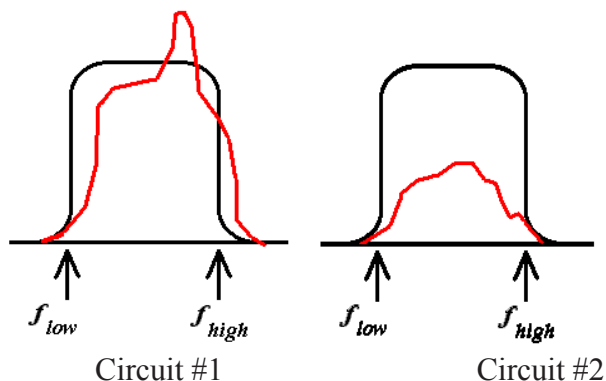
Circuit #1   Circuit #2

If you give the highest number to the response that minimized the square of the error, you select circuit #1 as the more fit. If you normalize the responses and then give the highest number to the circuit with the minimum square of the error, you select circuit #2. Representing "fitness" with a single number is quite problematical, however, this is necessary to implement a simple natural selection of the fittest circuit.

Determination of a proper evaluation metric for a given circuit functionality is the central experimental goal of this project.

Procedure:

Objectives 1 – 3 are met through a work plan developed by the student with faculty guidance. Developing the specific procedures to meet the objectives is part of the purpose of this experiment. Objectives 4, 5 are expected results. Objective 2 addresses the implementation of the evolutionary portion of the system. We are designing a system that starts by generating a population of circuits intended to be band pass filters meeting given performance requirements. Each of the initial generation of circuits will be created by randomly selecting the number of components, randomly selecting the parametric values of each component and randomly selecting the connections between them. The complete circuit will be represented by a specific "gene". The gene is constructed like a pSpice netlist. A gene fragment example is shown here.

```
N012  N014    Resistor    6K
N012  N013    Resistor    4K
N013  N015    Capactior   .2uF
N013  N014    Xstor B-E   2N2222A
N013  N017    Xstor B-C   2N2222A
N017  N018    Resistor    12K
N014  N019    Resistor    20K

 ↑      ↑         ↑         ↑
node 1  node 2  component  value
```

Each line of this "gene" is similar to a step in a DNA ladder. Genes representing thousands of circuits can be generated, and then subsequently modified by mutations, cross-linking, segment deletions, and all of the other changes that can occur with DNA in a biologic system.

Objective 3 concerns the development of the "fitness" metric to evaluate each of the individual circuits. This fitness number is used to select the circuits that will be the basis of the next generation of circuits. The result obtained at the end of the summer research will be reported later.

Comments: We expect two types of results. First, is the suitability of this project for a student summer research project. Development of the controlling software such that a general user can specify a circuit performance to be obtained should take about 1/3 of the ten week summer research period. Creating the gene structure and adapting it to work with an analog circuit simulator such as pSpice should take about 1/3 of the period. This leaves 1/3 of the period for studying the fitness metric and exercising the system to obtain experimental results. Second is the performance of the circuit itself. We expect to show that the natural selection system can evolve circuitry that will meet or exceed the target performance parameters.

One of the hurdles to the evolutionary approach is the amount of computer processing necessary to evaluate the behavior of the thousands of individual circuits in each generation of evolution. This hurdle can be lowered considerably by using a cluster of parallel processing computers. Developing a parallel processing version of the evolutionary design system is an obvious research project for the future.

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SECURITY ACCESS USING FACIAL RECOGNITION
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Security Access Using Facial Recognition

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Objective: This research is aimed at developing a facial recognition system that can be used to control access to a secure area.

Equipment and Materials:

National Instruments LabVIEW 7Express – graphical programming language used to implement the facial recognition system

National Instruments IMAQ (Image Acquisition) – LabVIEW compatible image acquisition library, controls the image board, which converts the image from analog to digital

National Instruments IMAQ Vision Assistant 7.0 – LabVIEW compatible image acquisition interface, allows user to acquire and manipulate the images from a menu of selected library functions

National Instruments IMAQ Vision 6.1 – LabVIEW library containing 300+ image and vision library functions

Microsoft Excel Spreadsheet – spreadsheet format used to store the database records

Sony XC-ST50CE monochrome analog camera

Fujinon HF 16A-1 16mm C-mount camera lens

National Instruments IMAQ PCI-1409 Vision Board

 Introduction: Security measures around the world are becoming more complex

and technically advanced. Those who wish to gain access to information protected by

familiar security devices, such as swipe cards and personal identification numbers, are

slowly figuring out how to beat these systems. The question now arises, "What security

measures are reliable enough to allow access when needed, but still assure that the person

gaining access to the information is, indeed, the correct individual?"

To answer the question, we must evaluate all known security measures and devices. Known security measures have been categorized into three levels:

1.   Something you have, such as a key or swipe card. This is the least secure of the three levels, because physical items can be easily lost or stolen.

2.   Something you know, such as a login and PIN. Although more secure that level 1, this level of security can easily be breached by thieves, as well. Human nature is to use the same login and PIN for all of our secure programs and information due to the limited capacity to remember a separate login and PIN for each. Also, the same tendency to forget passwords can tempt an individual to write the password down and place it near his/her computer or in his/her wallet or purse.

3.   Something you are, biometrics. Biometrics is defined as the use of physiological characteristics and behaviors of an individual to determine identity. Some examples of biometrics includes fingerprinting, retinal scans, iris scans, handwriting analysis, voice recognition and facial recognition. This is by far the most secure of the three levels. Theoretically, when a person is identified by physiological characters unique to him/her, no unauthorized individual will gain access to the protected information.

The answer to the above question is some combination of all three levels of security. There are no experts claiming that biometrics alone can solve security issues,

however, biometrics may be the key to validating the level 1 and level 2 security measures. For example, a swipe card may be used to pull up the immigration record for an individual entering the United States at a valid checkpoint. Then a facial recognition system will verify that the individual who possesses the swipe card is, in fact, the individual who filed the paperwork and has been granted entrance into the United States.

Facial Recognition

Facial Recognition, a division of biometrics, specifically, uses the location and measurements of certain unique facial features of an individual to determine identity. The advantage of facial recognition over other biometric techniques is that it is not obtrusive and is passive, that is, facial recognition does not require the entering of the human body, such as lasers for retinal scans, and does not require that a person be aware of the action [Mullins].

There are two types of facial recognition systems, live surveillance and still imaging [Mullins]. Live surveillance can be extremely difficult to implement because it requires detection that an object has entered the field of view, capturing the image properly, locating a face in the image, and analyzing the face. Still images are a single frame image of a human face, such as a mugshot. Within these types of facial recognition are two different purposes for which facial recognition are used, identification or verification [Mullins]. Identification is when the identity of the subject is not known. In this case, all of the identities in the database of know individuals must be searched for a match. The order of this search is 1:N, where N is the number of individuals in the database. Verification is when the subject claims an identity and only

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the record for the claimed identity is compared with the current subject. The order of the verification search is 1:1, where one current image is only compared to one database record.

The science of facial recognition systems is based on identifying, measuring, and comparing nodal points on the face in an image. Each human has approximately 66 unique nodal points on their face [Mullins]. Measurements are made between each of these nodal points to determine a person's unique identity. The key to proper measurement is locating the center of the eyes. Distance between eyes, distance to the tip of the nose, distance to cheekbones, and other similar measurements can be made to create a unique facial record for each individual. This record gives us a 'biometric signature' of the individual. It is important to note that, although many facial recognition systems do store an actual image associated with each record in the database, that the biometric signature is a mathematical or numerical file, not an image.

Statement of Problem

This research involves improving an existing facial recognition system, designed by undergraduate students at Norfolk State University, to meet accepted industry standards of currently utilized commercial facial recognition systems and to implement the security system at a mock entryway to a secured area. This facial recognition system uses computer vision and image processing techniques to accomplish the verification of a claimed identity of a subject by comparing a the biometric signature of a current still-image 'mug shot' known as the 'probe' to a record stored in a database or 'gallery' of known subjects. This procedure is currently implemented in a variety of environments,

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however, the use of LabVIEW assisted hardware and software will make this accomplishment unique.

Photographing Environment

Photographing technique is extremely important to achieve a successful Facial Recognition algorithm. A photographing booth is being used by the research team to control the photographing environment for the database images. The booth is a frame with a back panel and two side panels covered with a solid white cloth. The frame is constructed from PVC tubing and is approximately five feet tall, four feet wide, and two feet deep. The white cloth panel creates a constant background so that the facial image will not be confused with background noise. The lighting is still under experimentation.

A review of the *Best Practice Recommendation for the Capture of Mugshots* by N.I.S.T. [McCabe] has led the research team to the following conclusions for the capture of database images:

1. All images will be full-face frontal images.
2. Subjects should not wear any eyeglasses during database enrollment or during identity testing.
3. Lighting should originate from at least three (3) points for balanced illumination.
4. All image files will be saved in JPEG format.

Issues such as distance of subject from camera and centering of individual in the field of view will be decided when the final positioning of the camera in relation to the secured entryway is known.

Measurement Algorithm

The existing facial recognition system used eleven (11) measurements to create a biometric signature for each individual in the database. The existing measurements were:

1. Distance between the left eye and right eye,

2. Distance between the nose and right eye,

3. Distance between the nose and left eye,

4. Distance between nostrils,

5. Distance between the midpoint of the eyes and nose,

6. Distance between the midpoint of the eyes and hairline,

7. Distance between the nose and left cheek,

8. Distance between the nose and right cheek,

9. Area within the triangle created by hairline, right cheek, and left cheek,

10. Angle between right eye, nose, and midpoint of eyes, and

11. Angle between left eye, nose, and midpoint of eyes.

The current research was aimed at bringing the number of measurements used up to eighteen (18). It was learned during research that a successful recognition system should compare at least 1/3 (18 to 22) of the 66 unique nodal points/measurements on the subject's facial image [Mullins]. This left the current research team with the task of

locating seven (7) additional measurements reliable enough to be used for recognition. However, before the new measurements were developed, the research team discovered that the existing algorithms used for the location of the hairline, right cheek, and left cheek gave inconsistent results on images where the subject's face was tilted. The solution to this problem was to determine the angle of tilt and then search for edges on a line of the same angle.

For the location of the hairline, the tilt was determined by taking the inverse sine of [the distance between the right eye and the left eye divided by the difference in the x coordinate of the right eye and left eye]. The x coordinates of the points 50 and 200 pixels above the center point of the eyes were located by multiplying 50 and 200, respectively, by the sine of the compliment of the angle of tilt. The y coordinates of the points 50 and 200 points above the center point of the eyes were located by multiplying 50 and 200, respectively, by the cosine of the compliment of the angle of tilt. The Edge Tool, provided by IMAQ Vision, was then used to search the line beginning at 50 pixels above the midpoint of the eyes and ending 200 pixels above the eyes to locate the first distinct edge. This, theoretically, returns the location of the edge of the hairline. (NOTE: This algorithm has not been testing on any individuals with bangs.)

For the location of the left cheek, the angle of tilt was determined by taking the inverse tangent of [the difference in the x coordinates of the midpoint of the eyes and the nose divided by the difference in the y coordinates of the midpoint of the eyes and the nose]. The x coordinate of the points 50 and 200 pixels to the right of the nose were located by multiplying 50 and 200, respectively, by the sine of the angle of tilt. The y

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coordinate of the points 50 and 200 pixels to the right of the nose were located by multiplying 50 and 200, respectively, by the cosine of the angle of tilt. The Edge Tool, provided by IMAQ Vision, was then used to locate the first distinct edge on the line beginning with the point 50 pixels to the right of the nose and ending with the point 200 pixels to the right of the nose. This, theoretically, returns the edge of the left cheek. (NOTE: In an image displayed on the computer monitor, the subject's left cheek will appear on the right side of the image and the subject's right cheek will appear on the left side of the image.)

The edge of the right cheek was located by reversing the direction of measurements made in the algorithm used to locate the left cheek. Once the research team was comfortable that these points were being located accurately, the new measurements could be developed.

The first measurement that was added used the Polygon Area VI, provided by IMAQ Vision, to find [12] the area with the triangle created by the nose, left eye, and right eye. Then the Maximum Horizontal Clamp VI, provided by IMAQ Vision, was used twice to find [13] the width of the right eye and [14] the width of the left eye.

Database

The database records needed for this facial recognition system will require six (6) initial images of the known individual. All measurements will be made on each of the six images using the measurement algorithm and a mean and standard deviation will be calculated for each measurement for each known identity. The mean represents the

expected value for the measurement, or the value for which the measurement has the highest probability of being equal to.

$$m \equiv \frac{1}{n} \sum_{k=1}^{n} x_k,$$

Figure 1: Formula for calculating mean, where n is the number of values (six in this case) and x_k are the individual values (measurements for each image in this case)

The standard deviation represents the distribution of the known/measured values around the mean.

$$s_N = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2}.$$

Figure 2: Formula for calculating the standard deviation, where N is the number of values (six in this case), $\bar{x}$ represents the mean, and x_i is the individual values (measurements for each image in this case)

The research team has begun to develop a database of known individuals. The current database has only four records. Again, due to the sensitivity of the measurement algorithm to lighting, the addition of an individual to the database and the testing of the database images can be time consuming and, therefore, a slow process. To speed up the testing process, a request has been made to the National Institution of Standards and Technology for a copy of the FERET (Facial Recognition Technology) database of images that can be used to test the measurement algorithms.

Identity Test

Once the database is created, the program can now test whether a new probe image (either stored image file or acquired mugshot image) matches the biometric signature of a record in the database. First, the measurement algorithm is applied to the unknown image. The probe measurements are then compared to the mean and standard deviations for the measurements stored in the record for the claimed identity. If the probe measurement falls within the range [mean minus three times the standard deviation] and [mean plus three times the standard deviation], then the measurement is considered valid for that subject and it's weighted valued is added to the final score. If the probe measurement falls outside of the set range, the measurement is considered invalid and no value is added to the final score. Once all measurements have been compared in the same manner, the final score is analyzed. The value of the final score will be between zero and one thousand. A final score of 700 or higher, signifies a 90-95% chance that the subject in the current image is the claimed individual.

Creating a Main Switchboard

Another accomplishment of this research team was the development of the Main Switchboard. The Main Switchboard will allow users of the facial recognition system to access all functionality of the program from one front panel with a drop-down menu. The menu choices include:

Create Templates for an Individual

Add Individual to the Database

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Test the Claimed Identity of a Live Image

Test the Claimed Identity of a Stored Image

This main switchboard will bring up the front panels associated with each sub-program in a VI Display window on the front panel of the Main Switchboard.

Testing the Facial Recognition System

Once the facial recognition system is functioning properly, the system needs to be tested. There are some key error rates that need to be calculated to determine the true success rate of the program: False Match Rate, False Non-match Rate, and Failure to Enroll Rate [Nanavati]. False Match Rate, sometimes referred to as *false acceptance rate*, is the rate at which the system incorrectly identifies the probe image as matching a record that is not the correct identity. This rate is highly scrutinized when testing biometrics systems, as the purpose of these systems are to protect information from unauthorized users. If an unauthorized user gains access to secured information due to a FMR, the security of the information is breached.

False Non-match Rate is the rate at which an authorized user is incorrectly identified as not matching the database record, which does indeed belong to them. This rate is also considered as very important when a biometric system is being evaluated, because being denied access to information for which an individual is authorized or even the possibility of being locked out of a system can cause serious inconvenience. The other cost of high FNMR is a secondary security system, which must still be in place to handle false non-matches, such as a backup biometric or login and password system.

Failure to Enroll Rate is the rate at which new individuals being added to the database cannot be correctly evaluated through the measurement algorithm. This could be due to non-distinct facial features, a system that has been calibrated to a particular facial type, or user training. Failure to Enroll rates can also lead to high cost for a backup security system that is used to identify individuals that were not able to enroll in the biometric database. Interestingly, adjusting a system to decrease Failure to Enroll rates will often increase the False Non-match Rates, because individuals that cannot produce consistent biometric data may not be identified when they are tested by the biometric system.

The current success and error rates for the top ten (10) facial recognition systems have been tested and published by the Facial Recognition Vendor Test 2002 (FRVT 2002) [Phillips]. For images showing normal changes in indoor lighting, the top system had a 90% verification rate at a false match rate of 1%. However, when outdoor images were tested, the verification rates dropped to an alarming 50% at a false match rate of 1%. Some other findings by the FRVT 2002 were:

1. For each doubling of the database size for 1:N identification the verification rates decreased by 2 to 3%.

2. The top systems had an average of 6 to 9% higher verification rates on males than on females.

3. For each ten (10) years increase in age of the subjects, the verification rate increased approximately 5% through age 63.

4. As time elapses between enrollment and identity testing, verification rates decrease by approximately 5% per year.

5. Using software that provides morphable models on non-frontal images rotated either to the right or left increased the verification rates for one vendor from 26% using the non-morphed images to 84% using the morphed images.

Through these results, researchers and developers are given success rates and error rates to aim for when designing or improving facial recognitions systems. The FRVT 2002 also points out some areas of Facial Recognition that need significant improvement.

The research team has developed a mini testing program called TestAlgorithm.vi, which can test the measurement algorithm on any individual stored image. The right eye, left eye, and nose templates for that individual must be generated and stored before the testing program can be run on the image though. The algorithm test will return any of the nodal point locations that have one or more coordinate values equal to zero. This indicates that the point was not properly located, therefore, defaulted to the coordinate location (0,0). The algorithm test will also return the number of measurements (out of the 14 total calculations) that have a value equal to zero. A value equal to zero will indicate that the program could not properly evaluate the calculation. This TestAlgorithm.vi is a tool that can help the research team determine if the measurement algorithm is actually locating the desired points and calculating the specified measurements from those point locations. The measurement algorithm will be tested extensively on the FERET Database using this program.

Conclusion

In conclusion, the research team has accomplished some of the improvements to the existing facial recognition system that bring the program up to industry standard, such

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as the ability to test on stored images, as well as live images and the operation of the program from one Front Panel/Graphic User Interface (GUI). The goal of reaching eighteen (18) total measurements was not achieved during this research period. The previous eleven (11) measurements were increased to only fourteen (14), but during the next six months, the additional four (4) measurements should be obtained. The challenge to adding measurements to an identity algorithm is that the measurements must be reliable enough to produce unique values that can be used to determine an individual's identity based only on a facial image.

The algorithm works with 100% accuracy on stored images that were taken the same day that an individual was enrolled in the database; however, the success of the live image identity on any later date was mixed. Again, the determining factor for the reliability of this facial recognition system seems to be the lighting.

Future Work

Future work includes short-term goals, such as, the development of four additional measurements for a total of eighteen, and the testing of the facial recognition program and comparison to results obtained during FRVT 2002. Some long-term goals are to build a mock entryway to a secured area so that the facial recognition system can be further tested and demonstrated in real-life situations and the experimentation and integration of additional security measures to use in conjunction with the facial recognition system. Some security systems being considered are the design of a smart chip, iris scanning, and/or Personal Digital Assistant (PDA) integration with LabVIEW to accept login and passwords.

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GREEN ENGINEERING AT VIRGINIA TECH
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Green Engineering at Virginia Tech

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Key Words: Green Engineering, Green Concentration, Life Cycle Assessment

Prerequisite Knowledge: None

Objective: This paper reviews the success and failures of the Green Engineering Program at Virginia Tech over the past ten years. The history of the program is examined, including the steps to offering a 'concentration' in the area.

Introduction:

Virginia Polytechnic Institute and State University (Virginia Tech) is entering its 131st year. Founded in 1872 as Virginia's land-grant college with an initial enrollment of 43, Virginia Tech has grown to become the commonwealth's largest university with enrollment at roughly 26,000. The University offers over 200 degree programs through its seven undergraduate academic colleges. Its annual research expenditures exceed $150 million.

Virginia Tech's College of Engineering accounts for about one quarter of university students, both undergraduate and graduate, as well as the lion's-share of research expenditures. The College of Engineering consists of 10 degree granting departments plus the Division of Engineering Fundamentals – the home of engineering's common-first-year program. Virginia Tech's College of Engineering is unusual in that, in addition to the multitude of special interest groups, labs and research areas, the college contains a Green Engineering Program.

History:

In 1992, five faculty members and administrators within the College of Engineering began the quest to establish a program which would stress the environmental and societal implications of engineering activities. This group (Wayne C. Clough, now president of Georgia Tech), Malcolm McPherson (recently retired Dean of Virginia Tech's College of Engineering), Ronald Kander (Department Head, Integrated Science and Technology Department, James Madison University), Mike Vorster (David H. Burrows Professor of Civil and Environmental Engineering, Virginia Tech) and John Novak (Nick Prillaman Professor of Civil and Environmental Engineering, Virginia Tech) submitted a funding proposal to the University to support this program. The University's subsequent decision to provide continual funding for this program at about $200 thousand annually was praised within the College of Engineering. Department heads, deans and administrators agreed to provide cross-disciplinary support for the fledgling program. The program was given a two-fold mission: 1) establish a concentration in Green Engineering and 2)

ensure that every Virginia Tech engineering graduate had an understanding of the environmental and societal ramifications of engineering activities.

Organization:

This program was established with a part-time director and a seven-member steering committee. The director and six members of the steering committee were appointed by the dean of the college who, in turn, was the seventh committee member. The director would serve for three years while retaining a half-time involvement in his/her own department. Funding for the directors position was secured from the University's annual program support. Although the director's 'home' department continued to fund his/her full salary, the Green Engineering Program would reimburse that department by providing whatever funding was required to hire a teaching replacement. Members of the steering committee serve as unpaid 'volunteers', contributing their time and effort in support of the overall mission of the college. Whereas the program has had three directors over the course of its existence, steering committee members, by and large, have stayed with the program unless retirement or another job opportunity has presented itself. Each new director has been appointed from the ranks of the steering committee. No formal procedure or policies have been instituted regarding this program and the committee works on an ad-hoc basis.

Green Concentration:

Green Engineering encompasses all of the engineering and science disciplines, focusing on the design and synthesis of materials, processes, systems, and devices with the objective of minimizing overall environmental impact (including energy utilization and waste production) throughout the entire life cycle of a product or process. Green engineering might be considered environmentally conscious attitudes, values and principles combined with sound science, technology and engineering practice. Green engineering is, inherently, inter- and cross-disciplinary in nature. Each department within the College of Engineering includes this information to a greater or lesser degree as an imbedded and generally non-specific part of its curricula.

In order to provide students an opportunity to pursue a more in-depth and broader study of the environmental ramifications of engineering activities, the Green Engineering program developed a concentration in green engineering. The development of a green engineering minor was considered. University regulations required that such a minor be offered by the department conferring the green major, and the development of a green major was not an option. The concentration is identical to the minor in content. Students pursuing the concentration are required to complete eighteen credit hours in courses approved for that concentration.

Establishment of the concentration thus required the development and/or identification of appropriate courses. The concentration specifically identified three areas: 6 credit hours in 'core' green engineering courses; six credit hours in courses with substantial green content within a students major (in-discipline); and six credit hours of courses with substantial green content outside the students major (inter-disciplinary). Establishing this curriculum required three steps: the development of the core green engineering courses; the identification of existing

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in-discipline and inter-disciplinary courses; and the modification of other existing courses to add green content.

The Director of the Green Engineering program, members of the steering committee and representatives from each of the ten departments within the College of Engineering reviewed course syllabi, content and texts to identify courses which could be designated as 'green'. The steering committee further that the two core green engineering course would be an introductory course (Introduction to Green Engineering, ENGR3124) and a course dealing with life cycle assessment of products, processes and services (Environmental Life Cycle Assessment, ENGR3134). Funding was provided from the Green Engineering budget for the development of these core courses.

Establishment of the concentration satisfied part of the mission of the Green Engineering Program. It was recognized by members of the steering committee that a limited number of Virginia Tech's roughly 6000 engineering students would pursue this concentration. The second part of the programs mission was to ensure that all engineering students had some exposure to green engineering principles. To satisfy this portion of the mission, the program submitted a request for proposals from engineering faculty to add green content to existing courses. Proposals were requested annually, reviewed by the steering committee, and awards granted. This portion of the Green Engineering Program used the bulk of the annual budget, but in turn led to the development of scores of courses with substantial green content.

Core Courses:

The two core courses of the Green Engineering Program are ENGR3124 – Introduction to Green Engineering and ENGR3134 – Environmental Life Cycle Assessment. The courses may be taken in any sequence, however the introductory course is offered only during the fall semester and the LCA class only in the spring semester. Each course is a three credit hour course and is limited to students who have completed their freshman year academic requirements.

ENGR3124 is designed to introduce engineering students to global environmental issues – those issues that engineers should be cognizant of as world citizens and environmentally conscious engineers. Students in this course examine ways in which human and engineering activities impact the environment, and they are exposed to environmentally conscious design techniques. Enrollment in this courses ranges from 10 to 30 students and, as such, is conducted not as a lecture class but more as a colloquium. As a three-thousand level class it is appropriate to expect students to take an active part in the development and direction of class discussions. This approach becomes more difficult as class size exceeds twenty. As expected outcomes or learning objectives of this class, the successful student should be able to:

- List and discuss the major environmental problems, their causes and potential solutions
- Discuss how the engineering profession can take a proactive role in minimizing environmental problems
- List the principal environmental issues facing their particular engineering discipline and discuss how these issues can or are being addressed by professionals in that discipline.
- Utilize spreadsheets and simple simulation/programming techniques to analyze environmental problems and alternative solutions

- Discuss the importance of interdisciplinary teamwork in the solution of environmental and environmentally conscious design and manufacturing problems.

Topical coverage in this class includes the following:

- Global Environmental Issues
- Sustainability
- Environmental History
- Science, Systems, Matter and Energy
- Ecosystems: Components, Energy Flow, and Matter Cycling
- World Summit discussion and review
- Matter Cycling
- Evolution and Biodiversity
- Population Dynamics, Carrying Capacity and Conservation Biology
- Various Guest Speakers
- Food Resources
- Soil Resources
- Geological Resources: Nonrenewable Minerals and Energy Resources
- Energy Efficiency and Renewable Energy Resources
- Risk, Toxicology and Human Health
- Air and Air Pollution
- Water Pollution
- Climate Change and Ozone Loss
- Solid and Hazardous Wastes
- Economics, Environment and Sustainability
- Sustainable Cities: Urban Land Use and Management.

ENGR3134, Environmental Life Cycle Assessment, introduces students to the practical application of life cycle assessment (LCA) techniques for engineering products, processes and systems. LCA methodologies including inventory, impact assessment, improvement analysis and streamlining procedures are introduced. Other LCA applications including life-cycle design, ecolabeling, costing and public policy in the United States and abroad are addressed. Enrollment in this class ranges from fewer than ten to forty-plus. The smaller class size is much more conducive to discussion of issues whereas the larger class sizes are limited, logistically, to a lecture format. As expected outcomes or learning objectives of this class, the successful student should be able to:
- Apply LCA principles to products, processes and services
- Apply streamlining techniques to LCA applications
- Describe the benefits and limitations of an environmental life-cycle assessment
- Conduct an environmental life-cycle inventory
- Evaluate data sources
- Utilize available LCA software

Topical coverage in this class includes the following:

- Introduction to Life Cycle Assessment
- LCA methodology
- LCA software systems
- Streamlining techniques
- LCA data quality
- LCA case studies
- LCA applications
- Life Cycle Design
- LCA in Public Policy
- LCA in Europe
- Materials issues in LCA
- Business uses of LCA
- Systems Analysis

- LCA Valuation
- Product Development
- Waste Management

- Integrating LCA
- LCA – Future Directions.

Funding and Corollary Issues:

A portion of the initial annual funding provided by the University and designated for the Green Engineering Program was absorbed by the College of Engineering as standard policy to cover overhead and administrative costs. Of the remaining eighty percent, thirty percent was allocated to the salary of the director, secretarial support, and program administration costs. The remaining funds were provided to faculty within the College of Engineering in response to their proposals to develop new 'green' courses, or to modify existing courses. No funds were set aside or designated for teaching the two core green engineering courses, ENGR3124 and ENGR3134.

When the Green Engineering Program was established by the College of Engineering, deans, administrators and department heads agreed that teaching these two core courses would be considered a normal part of a faculty member's departmental duties. In financial terms, the Green Engineering Program was not required to 'buy out' the time of a faculty member who taught either of the core courses. This policy worked well for a number of years. Faculty from the departments of Biosystems Engineering and Materials Science Engineering volunteered and taught these courses as part of their departmental teaching loads.

With tightening budgets within the state, university, college and departments, this policy came under question, in contradiction of the original agreements. In the words of one administrator when asked about a potential teaching overload associated with the core green courses, 'these courses don't count.' Without active support from within each department for the Green Engineering Program, faculty in those departments were much less apt to volunteer to teach the core courses. In some cases the courses were taught as unfunded overloads. In other cases the Green Engineering Program absorbed the additional costs or provided funding for adjunct faculty to handle the teaching load. This issue has further been complicated because, at least recently, the majority of students taking these green core courses have not been candidates for the concentration; rather they are undergraduate engineering students taking these classes as either free electives or technical electives. The net effect has been the expenditure of funds by the Green Engineering Program to provide alternative electives to engineering students.

Departmental faculty within the College of Engineering have both research and teaching obligations, in addition to other requirements. Faculty who volunteer to teach one of the core courses in this program, unless granted release time by their department, are limiting their time for research activities. Without both college level and departmental support it becomes difficult to recruit faculty for these teaching assignments. In contrast, the Green Engineering Program, through its course development grants, has provided roughly $500,000 to faculty within the College of Engineering over the past ten years.

Milestones:

The 'green' concentration was formally approved by the university in 1999, although the first student to complete the sequence graduated the prior year. In the intervening years fewer than a dozen students have completed the concentration, although student interest in the program has been increasing. A measure of that student interest is the establishment in the fall semester of 2002 of a student run organization (SRO) dedicated to promoting the interdisciplinary goals of green engineering: The Green Engineering Society of Virginia Tech. This group meets on a regular basis, has developed a formal structure, and has an agenda which includes the 'greening' of at least one campus building.

During the summer of 2001, the Green Engineering Program initiated and hosted the 2001 Green Engineering Conference: Sustainable and Environmentally Conscious Engineering. Held at the historic Hotel Roanoke and Conference Center in Roanoke, Virginia, the conference attracted 120 attendees and 42 technical papers in seven technical sessions. The conference was co-hosted by the Chemical Engineering Branch of the Office of Pollution Prevention and Toxics, United States Environmental Protection Agency. The conference was conceived as a biennial conference, to be hosted by a different university or organization in subsequent meetings. Funding for the development of the conference and to cover expenses not met by conference fees was provided by the Green Engineering Program and by Virginia Tech's Center for Organizational and Technological Advancement. The conference was successful in providing a venue for discussion of issues related to green engineering, for providing a forum for the presentation of technical papers in the field, and for raising the awareness of Virginia Tech's Green Engineering Program.

The visibility of this program has afforded the director the opportunity to speak about the program to various audiences including the American Society for Engineering Education (ASEE) and the American Society of Civil Engineers (ASCE). Additionally, the director is a member of the Engineer's Forum for Sustainability and the International Engineer's Roundtable, both groups currently hosted by ASEE. Virginia Tech's recent re-accreditation by ABET under the EC2000 criteria noted the contribution of the Green Engineering Program to the mission of the College of Engineering.

Funding from the Green Engineering Program is provided annually to support the Green Engineering Lecture Series. This one credit-hour course includes weekly presentations by invited engineers, scientists, environmentalists, public officials and members of NGO's. The topics are generally related to the environmental consequences of engineering activities. This course allows freshman engineering students an opportunity to learn about the real-world conflicts between engineering and the environment. This course has proven popular with entering freshman, with enrollment typically near one hundred. It is a not-for-graduation class and, as such, should be difficult to fill, particularly freshman year.

The Green Engineering Program in concert with the Division of Engineering Fundamentals has developed a fall speakers series aimed at the freshman engineering students, but open to all members of the university community. This program was initiated in fall of 2000 with a presentation by Judge Hullihen Williams Moore of Virginia's State Corporation Commission. Judge Moore addressed an audience of two thousand plus on the responsibilities of engineers globally, environmentally, and as world citizens. This presentation was intended as a 'kick-off' to the fall semester and proved so successful that it became an immediate and integral part of the

fall semester. A second lecture has been added to close the fall semester and provide insight into the profession and motivation to continue academically.

Future:

The future for green engineering is established, generally. With the world population exceeding six billion, the desire to raise the standard of living for all people, and the limited world resources, green engineering principles must be incorporated widely. The future of the Green Engineering Program at Virginia Tech is less certain. Annual funding for the program has been eliminated, due in large part to the fiscal pressures facing Virginia and her colleges and universities. The program will continue with funding carried over from prior years; however the Green Engineering Program is targeted for elimination under the current budget.

Efforts have been made to generate research funding for this program. The cross-disciplinary nature of the program, however, typically means that the Green Engineering Program competes with individual departments within the College of Engineering for the same research funds – not an efficient or desirable situation. As an undergraduate program only, it also lacks the graduate student resources necessary to an effective research program. Nevertheless, members of the steering committee continue to pursue funding to allow this important program to continue.

Biography:

Mr. Gregg is the Director of Virginia Tech's Green Engineering Program. He is an Associate Professor in the Division of Engineering Fundamentals, a former chair of ASEE's Freshman Programs Division, and a co-founder of Virginia Tech's Frith Freshman Laboratory. He has considerable experience in computer aided design and manufacturing and pursues interests in sustainability and engineering education.

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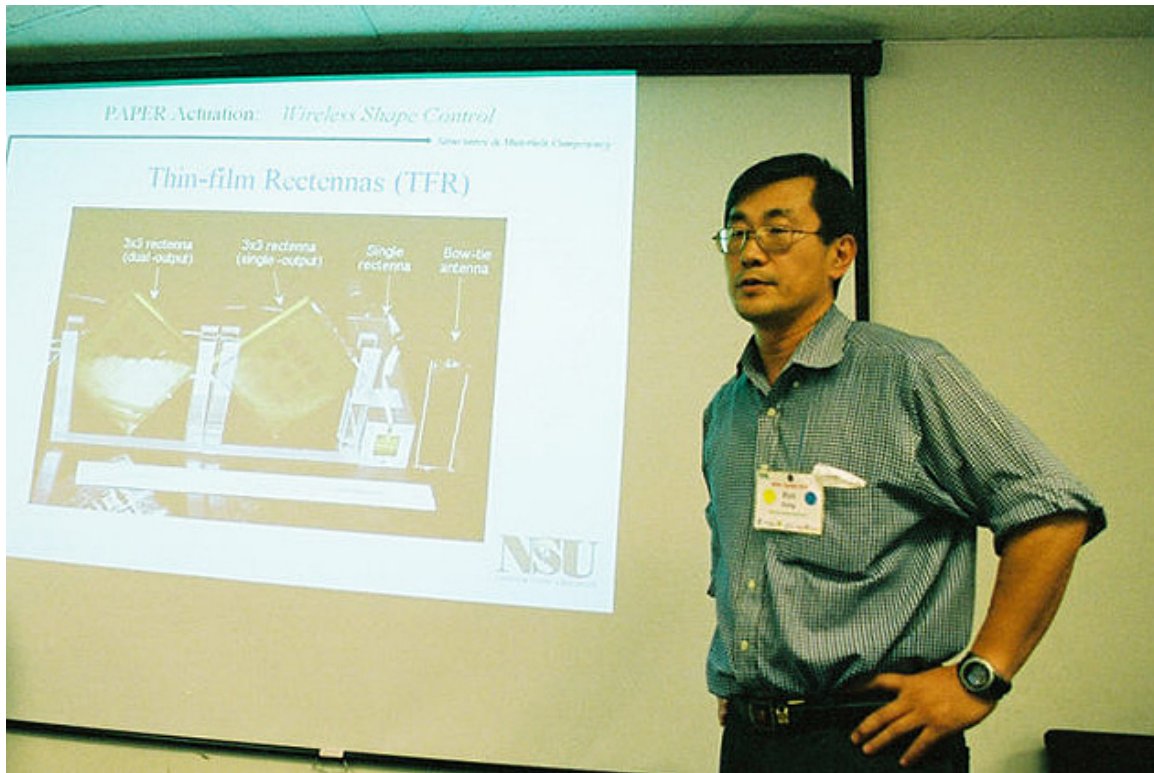
Kyo D. Song

Microwave Controlled Paper Actuator

National Educators' Workshop
October 19 - 21, 2003
at Newport News and Hampton, VA

Kyo D. Song, Walter Golembiewski, Jae-hwan Kim*, and Sang-hyun Chu**

Department of Engineering, Center for Material Research, Norfolk State University
*Department of Mechanical Engineering, Inha University, Korea
**National Institute of Aerospace

Key Words: Microwave and Paper Actuators

Prerequisite Knowledge: Basic knowledge of electronics, electromagnetic wave propagation, smart materials, rectenna operations

Objective: To provide the proof of concept that papers can be actuated by microwave power.

Equipment and Materials:
1. Anechoic chamber
2. Narda X band horn antenna model 601A (8.2 - 12.4GHz)
3. JPL 3 x 3 rectenna array
4. Hewlett Packard 8684B signal generator (5.4 - 12.5GHz)
5. Logi Metric Amplifier
6. Adjustable recycle time delay relay (HDFA Series by Amperite)
7. Hameg Instruments Oscilloscope (HM1507 150MHz 200Ms/s Analog/Digital)
8. Tekronix DMM916 (Analog/Digital Multimeter)
9. Coaxial cables and wiring fixtures
10. Electro active paper actuators

Introduction:

An experimental study of an electroactive paper actuator driven by microwaves is presented in this paper. A proof of concept experiment using paper materials has been set up and demonstrated using microwaves. The smart paper actuator system driven by microwaves may have applications, such as bio-mimic flying objects and micro air vehicles (MAV).

Procedure:

A feasibility experiment was set up and demonstrated using a microwave source to provide the power needed to actuate the electro active paper materials, as shown in Fig. 1.

A combination of signal generator and amplifier provided 20 W of microwave power to a Narda horn antenna at a frequency setting of 8.5GHz. The 20 W microwave power irradiated a JPL (Jet Propulsion Laboratory) 3 x 3 rectenna array. The rectenna, which is a rectifier and an antenna, converts the microwave power into DC power. The horn antenna, the 3 x 3 rectenna array, and the required wiring fixtures were inside an anechoic chamber as shown in Fig. 2(a) and 2(b). All other items listed in the equipment and material section were externally connected to the horn antenna and the rectenna via a backplate at the rear of the chamber. The Narda horn antenna is connected to the amplifier by a coaxial cable, and the signal generator is connected to the amplifier by a separate coaxial cable. The 3 x 3 rectenna array is connected to the exterior of the anechoic chamber by means of a dual output BNC connector. The distance between the horn antenna and the 3 x 3 rectenna array was 65 cm.

Comments:

In this experiment, the Narda horn antenna's 20 W microwave power was converted into a measured 72 V DC by a digital multimeter as indicated frequencies response in fig. 3. The estimated current being produced from the 3 x 3 rectenna array was 0.38mA. This was computed using various measured resistor values and the measured voltage across each resistor. The DC voltage output of the 3 x 3 rectenna array was connected to the resistors in separate operations, and the current through each of the resistors was calculated.

The experimental setup for measurement of the paper is shown in Fig. 4. The host paper is regenerated cellulose, so called cellophane. Coating for the both sides were made by gold sputtered.

Through the electro-active effect, paper has the capability to expand or contract, based on the polarity of the voltage applied. When the applied voltage is positive, paper actuator will flatten, and if the applied voltage were negative, the paper arches.

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Dr. Kyo D. Song is a P.I. of Faculty Awards Research (FAR) funded by NASA starting March 5, 1998 to March 4, 2002. He has been involved in many research projects, such as: Hypersonic Flow Research, Testing high temperature materials for Scram-jet Engine Components, Study on effects of atomic oxygen on space materials, and Smart materials research for Next Generation Space Telescope (NGST) under NASA supported grants. Dr. J. Kim, a professor at Inha University, was working as a research scientist at NASA Langley Research Center. His specialized area is smart materials research, especially paper actuators. Dr. Golembiewski is an Associate Professor working at Computer Technology. He has considerable experience in the design and testing of circuitry and communications. He also received a FAR grant staring from January, 2003 to 2005 from NASA. Dr. Chu is a research staff at National Institute of Aerospace (NIA) working at bio-nano battery area in cooperation with NASA research team.

Note: * The subject mater is under the invention disclosure (LAR 15754-1) at NASA Langley Research Center.
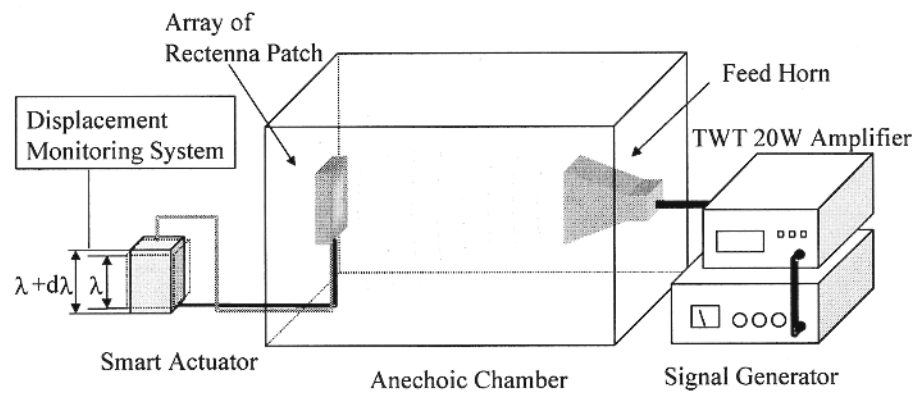
Fig. 1. Experimental setup for microwave-driven Thunder Actuator

(a)

(b)
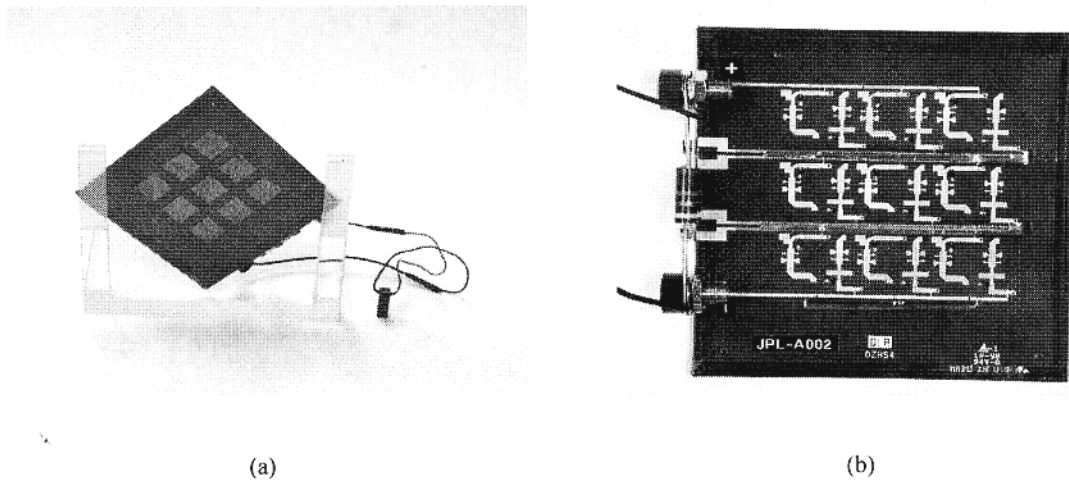
Fig. 2. The photograph of JPL 3x3 patch rectenna: (a) the rectenna with the multilayer piezoelectric actuator and (b) microstrip filter and rectifier circuit.
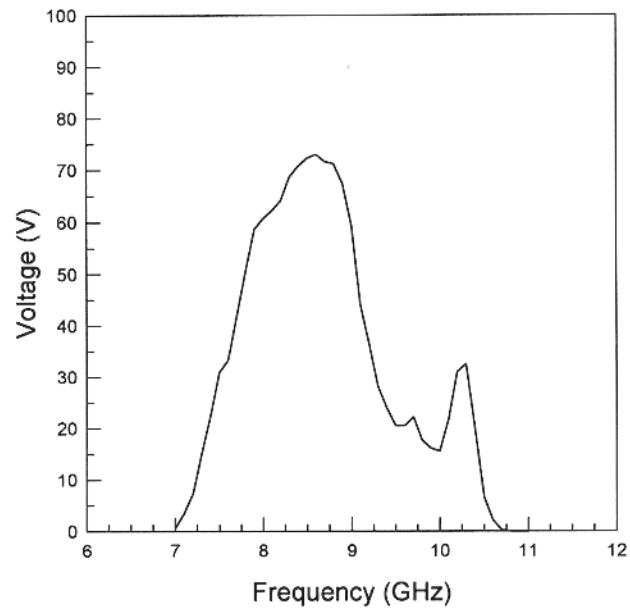
Fig. 3.   Frequency effect on voltage output generated by   h
          3x3 patch rectenna (100,000 Ohm) at 25" from   it
          feed horn with constant transmitted power of
          1.1 W.
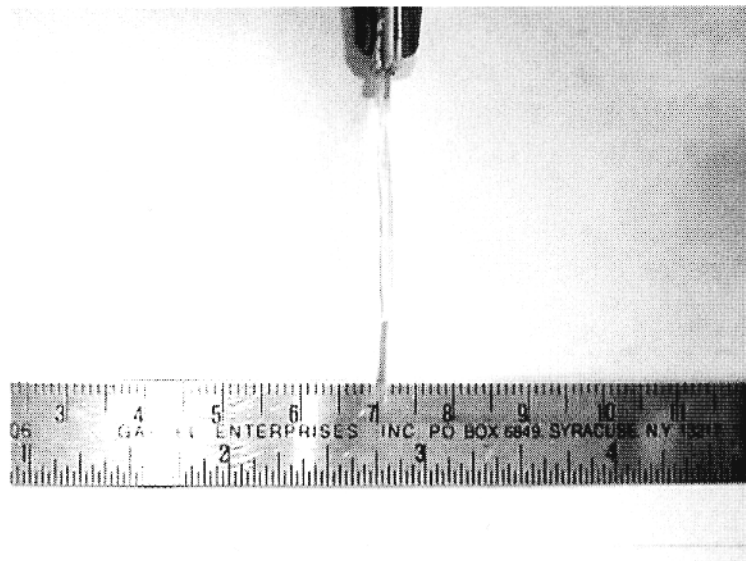
Fig. 4. Paper Actuator

703
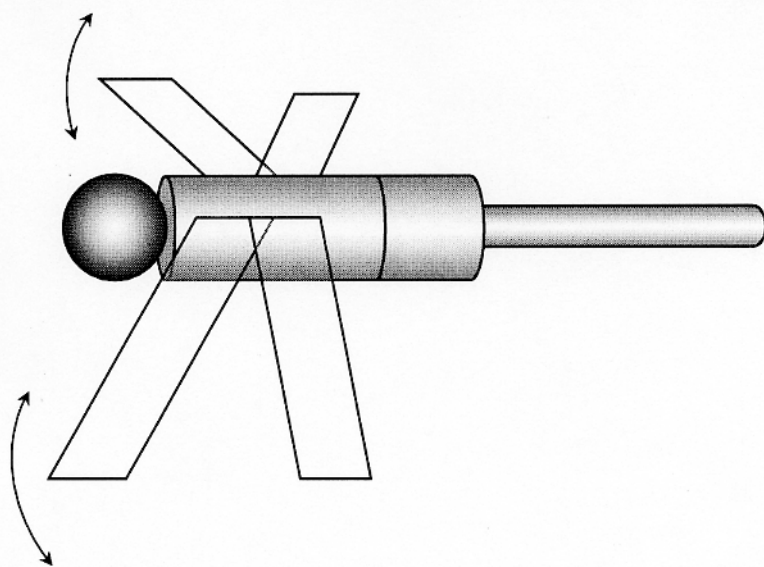
Fig. 5. An insect-like flying object as an application

POWER LOSS IN ELECTRONIC DEVICES: BIPOLAR AND FETs TRANSISTORS

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POWER LOSS IN ELECTRONIC DEVICES

In today's ever changing world, technology is also changing. Engineers, designers, and manufactures are the backbone of the technology world. To come up with new ideas and enhancements product or devices, these men and women have to sit and consider all of the functions, parameters, and measurements they desire out of their products or device, they have to think of almost every little obstacle they could face during their products operation. In doing so, a lot of time and energy is spent on the topic concerning Power loss. Power loss is described as the "losses" in a device due to normal or abnormal operation. There are a variety of effects that Power loss can have on a device, such as wildly varying line voltage before stabilizing, power repeatedly cycles on/off, severe interference occurs when power restored, and/or large surges when power restored. Not only does Power loss have adverse effects on components and devices, but it can also cause damage. These damages can range from prolonged low voltage causing motors to overheat; to on/off cycling may damage power supplies, and even causing large surges at power restoration to damage equipment, relays, and disrupting system operation.

Power loss is generally caused by six major factors.

1.   Resistance
2.   Magnetic friction
3.   Electric Current
4.   Physical Vibration and Noise
5.   Electromagnetic radiation
6.   Dielectric loss

In this experiment we choose to compare two different types of transistor, the bipolar and FETs. In doing so, we hope to see how each one of these factors play a role in these devices power loss. But to figure this out, we must first understand our devices.

One of the most common types of transistors is the bipolar. Bipolar transistors are made of two different kinds of materials; these two types of semiconductor materials are called N-type and P-type material. The N-type refers to the way electrons move through the material. The P refers to the positive charges moving through the material. Each transistor has three leads or electrodes, in the bipolar; these leads are called the emitter, base, and collector.

Bipolar transistors are used for linear and mixed-signal processes. Moreover, bipolar microcircuits are the primary ICs used in satellite applications, because of their good radiation hardness. The most important parts that make use of bipolars are operational amplifiers, ADCs, DACs, comparators, analog switches, multiplexers, voltage regulators and pulse width modulators. Bipolar ICs constitute nowadays about 40% of the circuits used in satellite and strategic missile systems that require radiation hardness skills. Plus, almost every power supply uses bipolar transistors.

Compared with the FETs, bipolar transistors employ vertical current transport, which offers better utilization of wafer area and thus leads to higher power density. The bipolar approach may also offer higher linearity and higher power levels, superior power-added-efficiency, and smaller low frequency noise as necessary for high power amplifiers. The bipolar transistor also shows superior silicon efficiency, lower processing cost, importantly, its inherently low threshold voltage required for full enhancement, is ideally positioned for the shit to lower voltages.

The other transistor we selected to study is the FETs or Field –Effect Transistors. The Field –Effect Transistors combines the high impedance of the vacuum tube with all the other advantages of the transistor. The elements of the FETs are the gate, source, and drain, which are comparable to the base, emitter, and collector of a standard transistor. The FETs are mainly used as switching devices and enhancement devices for functions similar to those of the bipolar, but add more to components parameters.

Field-Effect Transistors offer many advantages over bipolar transistors. A major advantage is the reduced power required to drive the device. The FETs requires only a small charging current to turn on. Turn off of the FETs is also faster since there are no minority carriers to be recombined. Also during turn off current in bipolars tends to crowd and create hot spots. This can cause the transistor to fail in what is known as secondary breakdown. The secondary breakdown effect in FETs is almost nonexistent. Another important advantage to the use of FETs is that they have a positive temperature coefficient, which helps to distribute current when paralleling devices.

FETs are not universally used, however, because it has some major disadvantages. The biggest disadvantage it has is its large on resistance, a source of major power loss. To keep these resistances reasonable the breakdown voltage is kept low making them unusable in higher voltage applications. Another disadvantage to these devices is that they are generally more expensive than a bipolar of the same ratings.

Resistance is one of the basic factors of power loss as discussed previously. In FETs, the resistance of the drift region mostly limits the drain current. Because the drift region thickness determines the voltage blocking capabilities of the device, the drain current resistance increases with increasing blocking capabilities. Source impedance also effects the switching time; large impedance will slow switching time and increase power loss. In bipolar transistors, the input impedance and On-state resistance play a major role in its power loss. The input impedance is the resistance of a transistor's input. This determines the amount of current it will draw from the controlling circuit, coupled with the resistance through the two power leads of the transistor, this will cause a proportional voltage drop across the device.

Magnetic friction causes power loss in both transistors when, a ferromagnetic material is magnetized in one direction, it will not relax back to zero magnetization when the imposed magnetizing field is removed. It must be driven back to zero by a field in the opposite direction. If an alternating magnetic field is applied to the material, its

magnetization will trace out a loop. The lack of retraceability of the magnetization curve is the property Magnetic friction and it is related to the existence of magnetic domains in the material. Once the magnetic domains are reoriented, it takes some energy to turn tem back again, thus causing a power loss in the device.

Electric Current is the biggest cause of power loss in these two devices because as current moves it produces heat. This heat must be transferred in the devices to maintain the operating junction temperature within the specific range. It should be noted that the reliability and life expectancy of any semi-conductor are directly related to the maximum device junction temperature experienced. When the power flow is regulated by the controlled variation of series resistance, there occurs a waste of heat and loss of system efficiency. This power loss is most widely seen when these two resistors are used as a switching devices. A bipolar transistor dissipates energy from the saturation voltage across the collector and emitter, and the FETs dissipates energy from the resistance of the substrate.

Physical vibration and noise, is one of the simplest and oldest forms of power loss in electronics. In these two devices, Physical vibration and noise are the cause of disruption of the magnetic field, creates microphonics, phase hits, and FM effects. Physical vibration and noise are directly related to the packing of a device.

Integrated circuits are built out of individual transistors, which act as voltage-controlled switches voltage flows across the transistor substrate when charge is applied to the gate. This delivers charge to the gates of other transistors; interconnect wires, and other circuit loads. The electric charge consumes power and produces electromagnetic radiation, causing in the FETs a "single-event gate rupture". In the bipolar, the electromagnetic radiation causes the transistor to degrade as a result of the device's ability to have a high collector-base voltage rating.

Dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic fields. If the flow of current between opposite electric charge poles is kept to a minimum while the electrostatic lines of flux are not impeded or interrupted, an electrostatic field can store energy. This property is useful in capacitors, especially at radio frequencies. Dielectric materials that are widely seen in bipolar and FETs are ceramics, distilled water, paper, mica, polyethylene, and metal oxides. Dielectric materials play a role in the power loss in these two transistors due to its dielectric breakdown. Dielectric breakdown occurs when the voltage across a dielectric becomes to great—that is, if the electrostatic field becomes too intense—the material will suddenly begin to lose current, and in transistors, this could cause the degrading of digital signals.

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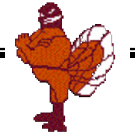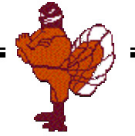
Δ MSE 4055 - Material Selection and Design
- MSE required, senior level
- Technical elective for ISE, ESM, ME, AOE, Arch, + others.
- Material Selection as it influences the outcomes of engineering design
  - in a general sense
  - green issues

Δ Methodology
- Identification of appropriate material selection indices
  i.   Define design objective
  ii.   Determine constitutive relationship
  iii. Separate design needs (extensive) from material response groups (intensive)
- 2-D material selection charts in the manner of Ashby
  M.F. Ashby, Materials Selection in Mechanical Design, 2nd Ed., B-H, Oxford, 1999.
- Cambridge Engineering Selector application software
  CES4.1, Granta Design, Ltd., 2003

Δ Disclaimers
- Illustrative of an approach
- Several layers of analysis required
- Not a final solution to the complex problem

Materials Science and Engineering
2003 National Educators' Workshop

Virginia Tech

Examples

- Selecting a material to solve a specific environmental problem
  - » *Identify a suitable alternative to asbestos as an insulating material*

- Enabling the routine assessment of green issues in generic engineering design
  - » *Lifetime Energy Consumption attributable to a component placed in a transportation system*

An alternative to asbestos insulation

Objective: Identify an insulating material to replace asbestos to reduce total lifetime cost (TLC).
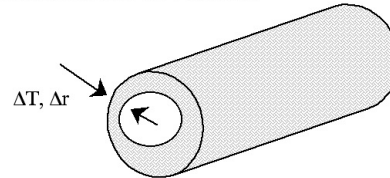
TLC = Initial Cost + Lifetime Operational Costs

(purchase price of the material) (e.g., due to heat losses)

ΔT, Δr

Design Needs
Δr = thickness (m)
ΔT = temperature difference (K)

Material Response Constants
ρ = material density (kg/m³)
C_M = per-mass cost ($/kg)
k = thermal conductivity (J/kg·K·s)

C_E = exchange constant ($ / J)

design requirements

$$\text{TLC} \ (\$ / m^2) \approx \rho \cdot C_M \cdot \Delta r + \quad k \cdot \frac{\Delta T}{\Delta r} \cdot \Delta t \cdot C_E$$

Material Contribution

C_E = Exchange Constant = $-value of Energy ($ / J)

Exchange Constant: the $-value of energy

Exchange Constant

Energy Source	Cost (US$ / MJ)
Coal	0.003 - 0 004
Oil	0.007 - 0.012
Natural Gas	0.005 - 0.008
Gasoline (US)	0.012-0.015
Gasoline (Europe)	0.03-0.04
Electricity (resistance)	0.02 - 0.06

from M.F. Ashby, Materials Selection: Multiple Constraints and Compound Objectives,
CUED/C-EDC/TR38, Cambridge Engineering Design Center, Cambridge
University Engineering, April 1996, p.1.13

Materials Science and Engineering
2003 National Educators' Workshop

Virginia Tech

Cambridge Engineering Selector (CES) Ver. 4.1

Cambridge Engineering Selector (CES 3.1)

Cambridge Engineering Selector (CES 3.1)

An alternative to asbestos insulation

Selected Candidate Materials

Property-range midpoint values
From *CES3.1*, 2000

The chart plots Thermal Conductivity, W/m·K (Relates to Cost of Energy Lost During Service) on the vertical axis (Increasing Service Cost) against Density · Price, US$/m³ (Relates to Initial Cost) on the horizontal axis (Increasing Initial Cost).

Materials plotted:
- Hokie Stone (Limestone)
- Cement
- Cellulose Insulation
- Cordierite Foam
- Mullite Foam
- Asbestos
- Vermiculite
- Plaster of Paris
- Cork
- PE Foam
- Glass Wool
- LD Flexible Polymer
- Glass Foam
- Melamine Foam
- PU Elastomeric Foam
- PU Foam
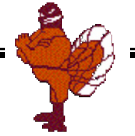
Lines of Comparable Lifetime Cost (relative to Asbestos)

Contours of Decreasing Lifetime Cost

Coal as an Energy Source
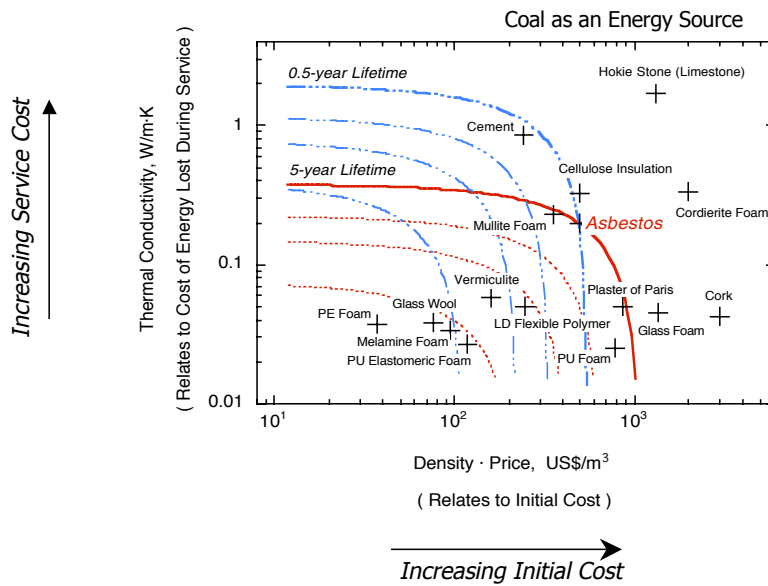
Assumed Design Needs

$\Delta T \approx$ 40 K

$\Delta r \approx$ 7 cm

Δt = 0.5 (blue) or 5 year (red)

Assumed Material Response

$k_{asbestos} \approx$ 0.4 W/m·K

$(\rho * C_M)_{asbestos} \approx$ 494 $/m^3
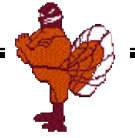
Ex. A component on a transportation system loaded in bending
- L fixed by design
- P predicted by design

Constitutive Equations:

$$\sigma = \frac{M \cdot c}{I} = \frac{3 \cdot P \cdot L^2}{4 \cdot b \cdot h^2} \qquad m = \rho \cdot A \cdot L$$

> P = distributed load (e.g., N/m)
> L = length (e.g., m)
> b,h = cross sectional dimensions (e.g., m)
>
> σ_ϕ = failure stress (e.g., MPa)
> ρ = density (e.g., kg/m^3)
> q = Energy content (e.g., MJ/kg)

$$m = \left(\frac{3}{4\sqrt{2}} \cdot P \cdot L^{7/2}\right)^{2/3} \cdot \left(\frac{\rho}{\sigma_f^{2/3}}\right)$$

Minimum mass (e.g., kg) required to fulfill requirements of strength-limited design (fixed beam aspect ratio)

$$Q = \left(\frac{3}{4\sqrt{2}} \cdot P \cdot L^{7/2}\right)^{2/3} \cdot \left(\frac{\rho \cdot q}{\sigma_f^{2/3}}\right)$$

Energy (e.g., MJ) required to fulfill requirements of strength-limited design, for q in MJ/kg

Objective: Minimize Lifetime Energy Consumption

Lifetime Energy Consumption (LEC) = Initial Energy Expenditure
+ Energy Expended during Service

$$LEC = \left(\frac{3}{4\sqrt{2}} \cdot P \cdot L^{7/2}\right)^{2/3} \cdot \left(\frac{\rho \cdot q}{\sigma_f^{2/3}}\right) + \left(\frac{3}{4\sqrt{2}} \cdot P \cdot L^{7/2}\right)^{2/3} \cdot \left(\frac{\rho}{\sigma_f^{2/3}}\right) \cdot C_E$$

Exchange constant relating
mass to energy expenditure

$$LEC^{/} = \left(\frac{\rho \cdot q}{\sigma_f^{2/3}}\right) + \left(\frac{\rho}{\sigma_f^{2/3}}\right) \cdot C_E$$

P = distributed load (e.g., N/m)
L = length (e.g., m)
b,h = cross sectional dimensions (e.g., m)

σ_f = failure stress (e.g., MPa)
ρ = density (e.g., kg/m³)
q = Energy content (e.g., MJ/kg)

724
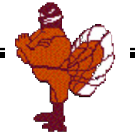
Estimating an Exchange Constant

Hypothetical Example:

- 3,000 kg vehicle: 14 mpg
  1,800 kg vehicle: 19 mpg
- Energy value of Gasoline ≈ 126 MJ/gal
- 50,000 mile lifetime

For the 3,000 kg vehicle and a 50,000 mile lifetime:

$$\frac{50,000 \text{ miles}}{\text{lifetime}} \times \frac{\text{gal. fuel}}{14 \text{ miles}} \times \frac{126 \text{ MJ}}{\text{gal.}} = 450,000 \frac{\text{MJ consumed}}{\text{lifetime}}$$

For the 1,800 kg vehicle and a 50,000 mile lifetime:

$$\frac{50,000 \text{ miles}}{\text{lifetime}} \times \frac{\text{gal. fuel}}{19 \text{ miles}} \times \frac{126 \text{ MJ}}{\text{gal.}} = 331,580 \frac{\text{MJ consumed}}{\text{lifetime}}$$

$$C_E \approx \frac{\Delta \text{MJ}}{\Delta \text{m}} = \frac{(450,000 - 331,580) \text{ MJ}}{(3,000 - 1,800) \text{ kg}} = 99 \frac{\text{MJ}}{\text{kg}}$$
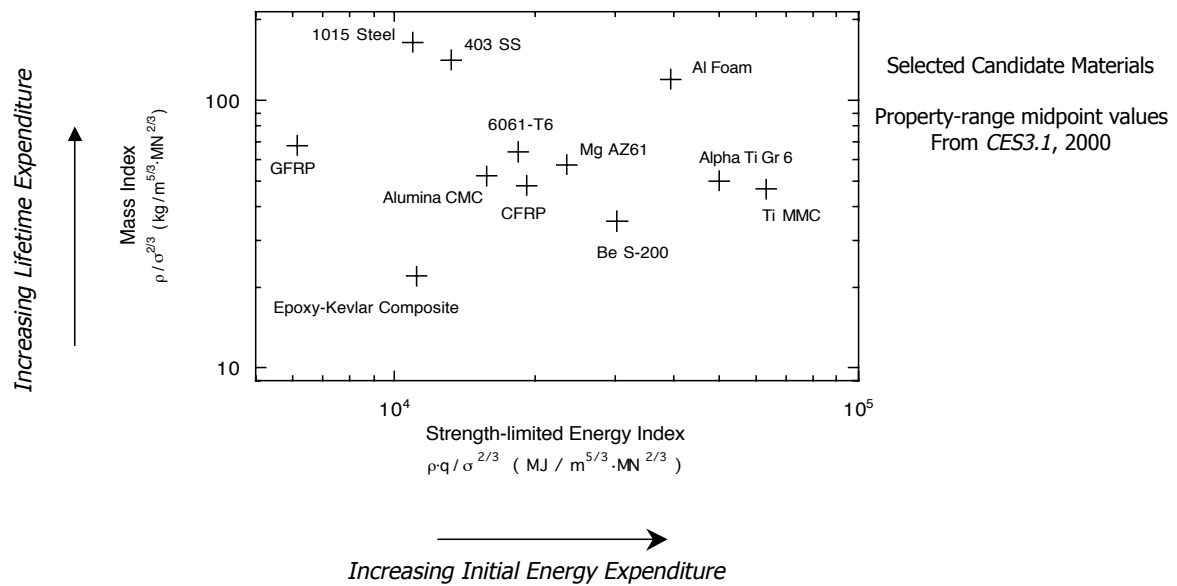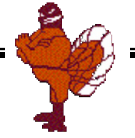
Selected Candidate Materials

Property-range midpoint values
From *CES3.1*, 2000

Increasing Lifetime Expenditure

Mass Index
$\rho / \sigma^{2/3}$ (kg / m$^{5/3}$·MN$^{2/3}$)

100

10

1015 Steel

403 SS

Al Foam

6061-T6

GFRP

Mg AZ61

Alpha Ti Gr 6

Alumina CMC

CFRP

Ti MMC

Be S-200

Epoxy-Kevlar Composite

10^4

10^5

Strength-limited Energy Index
$\rho \cdot q / \sigma^{2/3}$ (MJ / m$^{5/3}$·MN$^{2/3}$)

Increasing Initial Energy Expenditure

Materials Science and Engineering
2003 National Educators' Workshop

Virginia Tech

726

Increasing Lifetime Expenditure

Mass Index
$\rho / \sigma^{2/3}$ (kg / m$^{5/3}$·MN$^{2/3}$)

1015 Steel

403 SS

Al Foam

100

6061-T6

Mg AZ61

Alpha Ti Gr 6

GFRP

Alumina CMC

CFRP

Ti MMC

Be S-200

Epoxy-Kevlar Composite

C_E = 99 MJ/kg
(50,000 mi. lifetime)

C_E = 395 MJ/kg
(200,000 mi. lifetime)

10

10^4

10^5

Strength-limited Energy Index
$\rho \cdot q / \sigma^{2/3}$ (MJ / m$^{5/3}$·MN$^{2/3}$)

Increasing Initial Energy Expenditure

Materials Science and Engineering
2003 National Educators' Workshop

Virginia Tech

727
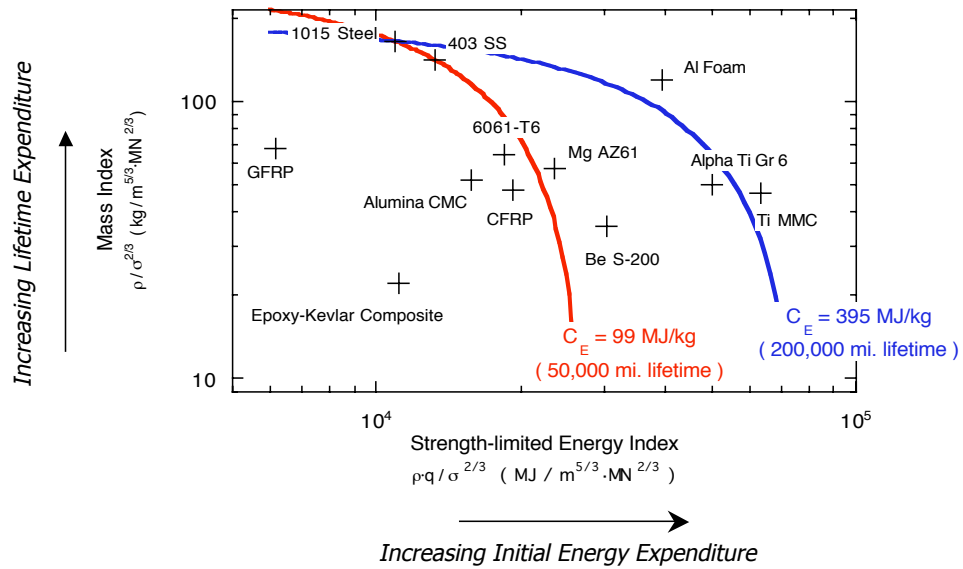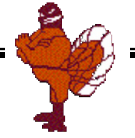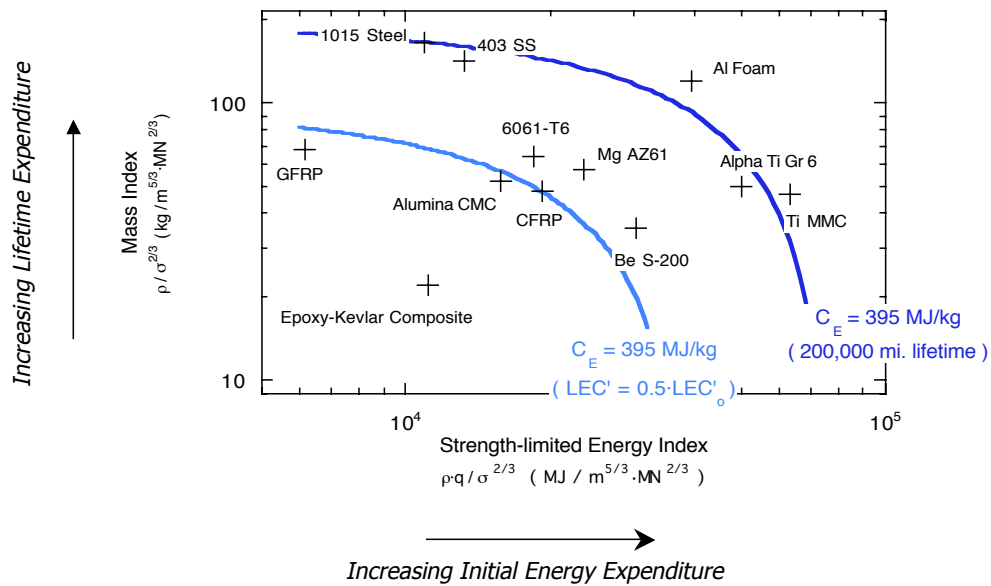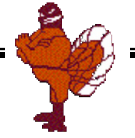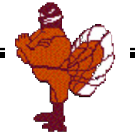
Summary

- Material selection is a decision-requiring event in design

- Green-based material selection indices and charts provide a means to *routinely* assess environmental issues relevant to the decision-making process

- One of several criteria necessary to consider in design

Note: Contents of this talk can be found in the following published manuscripts:

- S.L. Kampe, "Method to Incorporate Green Engineering in Material Selection and Design*," Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, (Proc. Int. Conf., Montreal, 17-19 June 2002), ASEE, Washington, D.C., 2002, pp. 1625.1-1625.7. http://www.asee.org/conferences/proceedings/search.cfm

- S.L. Kampe, "Incorporating Green Engineering in Materials Selection and Design*," 2001 Green Engineering Symposium Proceedings* (Proc. Conf., Roanoke, Virginia, August 2001), Blacksburg, 2001, pp. 7-1 – 7-6. Also featured at http://www. grantadesign.com/userarea/papers/cust1.htm.

Acknowledgements

- Virginia Tech College of Engineering
  - Green Engineering Program

- Virginia Tech Materials Science and Engineering Department

- Granta Design, Ltd.

JEFFERSON LABORATORY PICTURES

Thomas Jefferson National Laboratory

Applied Research Center

733
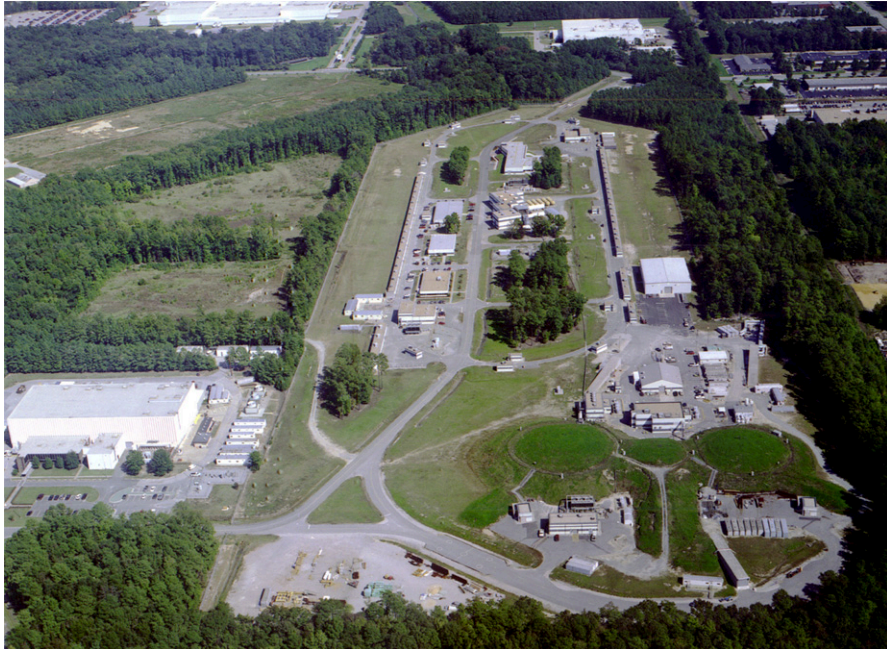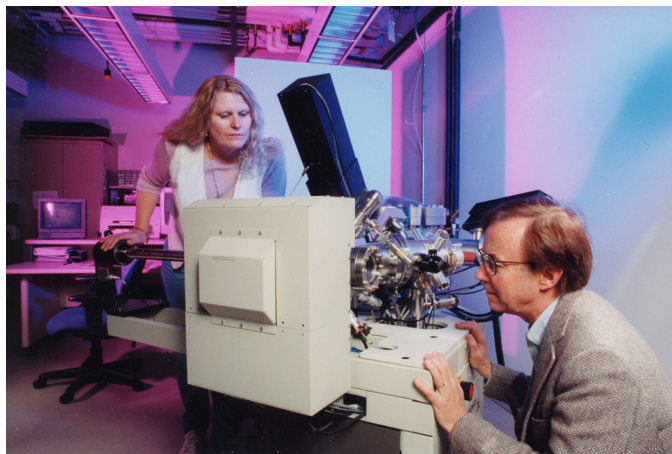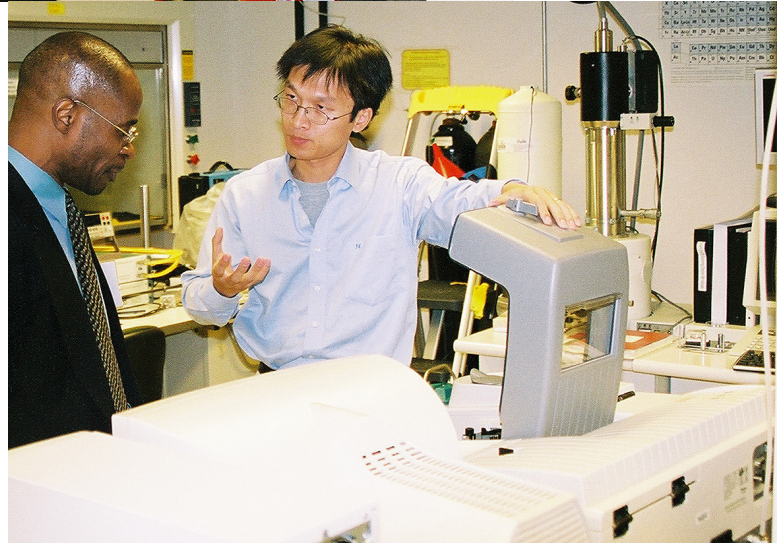
Mini Workshops

WELCOME
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Vice President of Education and Outreach
National Institute of Aerospace
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Hampton, Virginia 23666

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grossman@nianet.org
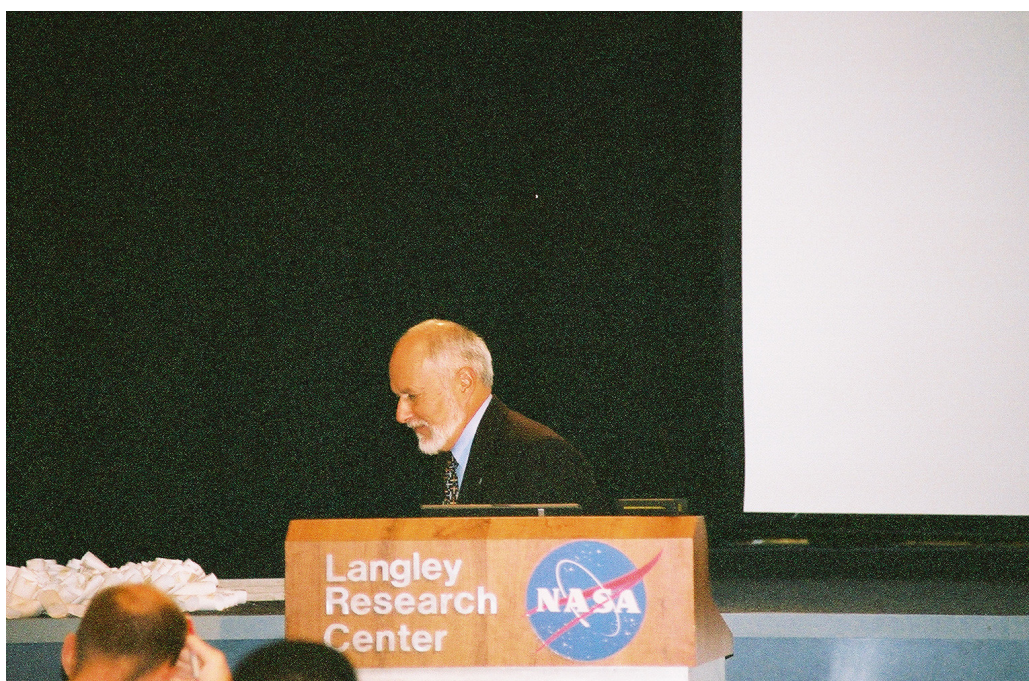
Bernard M. Grossman

AIR FORCE BASIC RESEARCH IN MATERIALS AND STRUCTURES

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Air Force Office of Scientific Research
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walter.jones@afosr.af.mil
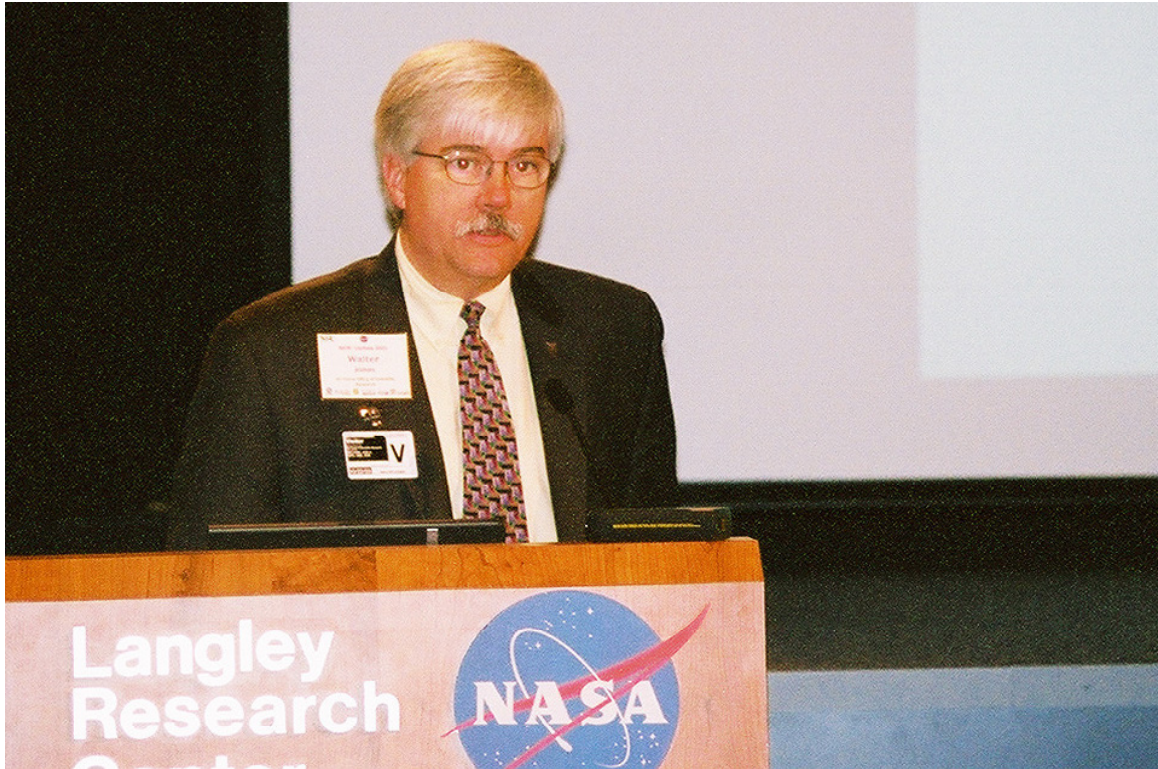
Walter F. Jones

Air Force Office of Scientific Research

The Basic Research Manager for the Air Force

www.afosr.af.mil

Air Force Basic Research in Materials and Structures

22 October 2003

Dr. Walter F. Jones
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AFOSR MISSION

AFOSR Orchestrates the Air Force Basic Research Program with Universities, Industry, Other Government Organizations, and the AFRL Technical Directorates (TDs)

Creating Revolutionary Scientific Breakthroughs for the Air Force

Revolutionary Capabilities - Making The Difference

F-117

UAVs

B-2

GPS

JDAM
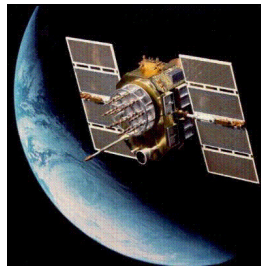
C-17 Globemaster

Lasers and Adaptive Optics

3

743

Effects – Multiplied!

- **"What I think was the key development was the integration of small teams of special operations soldiers with targeting devices in their possession, and then relaying that information to the air platforms"**

    - **Senator Jack Reed (D-RI)**

4

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Transformation?

- **Today or 1944? You make the call…**

AFOSR within the Air Force Research Laboratory (AFRL)

HQ AFRL

Technology Directorates

| Air Vehicles | Space Vehicles | Sensors | Materials and Manufacturing | Human Effectiveness |

| Propulsion | Directed Energy | Munitions | Information |

AFOSR
Basic Research is the Foundation!
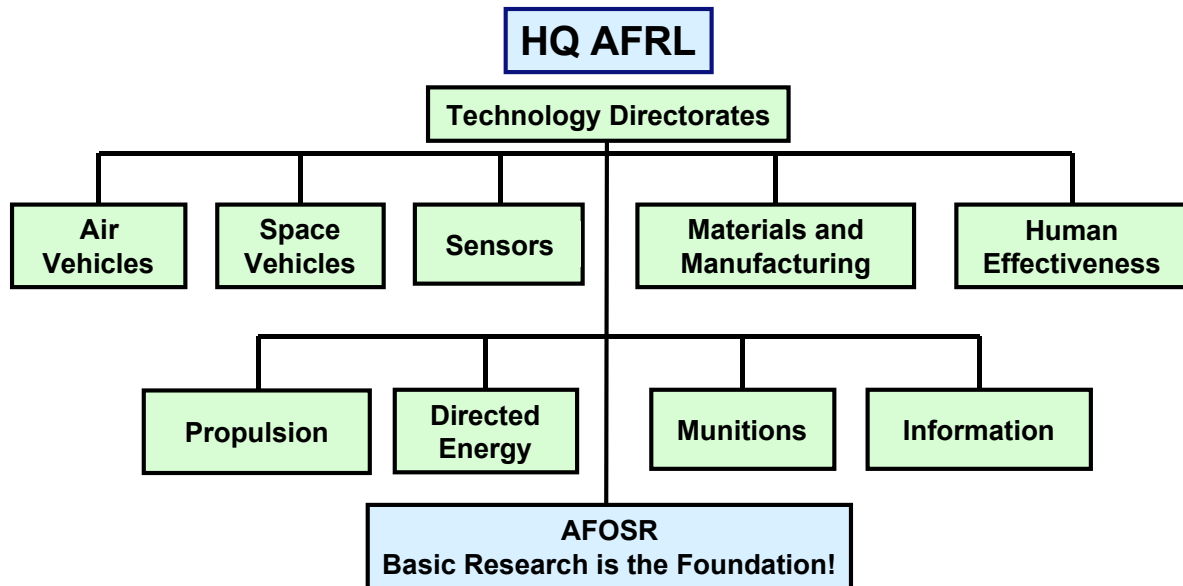
AFOSR is the *Single Manager* of Basic Research for the Air Force

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OFFICE OF SCIENTIFIC RESEARCH
Technology Thrusts
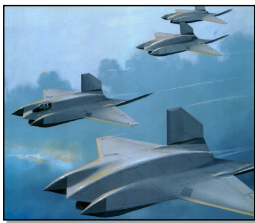
Aerospace and Materials Sciences	**Physics and Electronics**	**Chemistry and Life Sciences**	**Mathematics and Space Sciences**
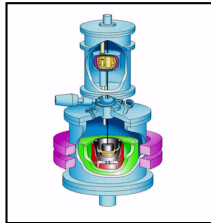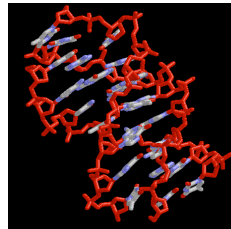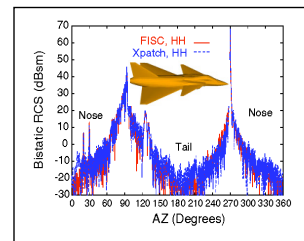
Sub-thrusts

- Solid Mechanics and Structures
- Materials
- Fluid Mechanics
- Propulsion

- Physics
- Electronics

- Chemistry
- Bio Sciences
- Human Performance

- Mathematics
- Computer Sciences
- Space Sciences

- **Aircraft and Space Structures**
- **Hypersonics**
- **Plasma Dynamics**
- **Materials Design**

- **Radiation Hardened Electronics**
- **Microsatellites**
- **Isomeric Energy Storage**

- **IR Biosensors**
- **All-Nitrogen Fuel**
- **Agile Laser Protection**

- **Identifying Hard Targets**
- **Quantum Computers**
- **Targeting Through Turbulence**

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Basic Research & Enabling Technologies

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AFOSR THEMES

- **Broad Interdisciplinary Areas** Funded and Managed to Achieve Significant Progress
- Topics **Generated by Program Managers;** Prioritized by AFOSR and TDs
- Enhanced Funding of Themes for 5 Year Minimum

Designated Themes

- Cooperative Control
- Plasma Dynamics
- Miniaturization Science for Space

- Biologically-Inspired Concepts
- Type II Quantum Computation
- Materials Engineering

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COOPERATIVE CONTROL

Multi-Mission Reconfigurable Assets

Undeniable Communication
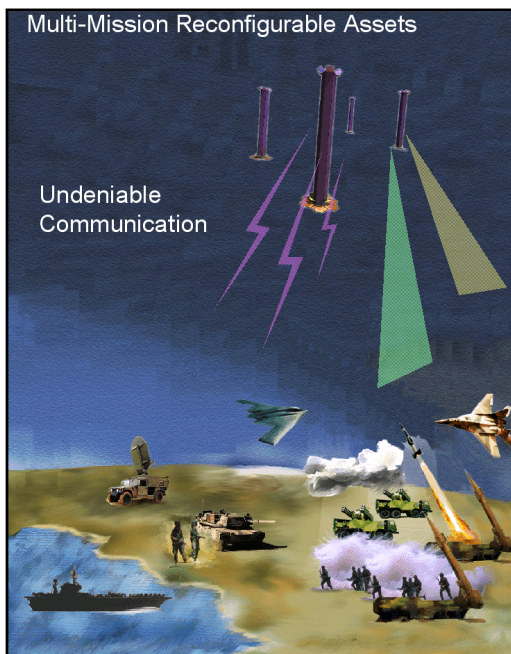
Objective

- Further develop theory of cooperative control systems

Approach

- Evaluate variety of revolutionary and evolutionary technologies
- Include applicable technologies into cooperative control systems

Payoff

- Autonomous swarms of UAVs
- Development of affordable "smart" weapons

9

BIOLOGICALLY-INSPIRED CONCEPTS

Objective
- Provide biologically inspired technology

organism

tissue

Infrared sensor

protein

molecule

Approach
- Explore living systems down to molecular level (molecular biology is nanobiology)
- Develop chemical models & engineering concepts

Payoff
- Increase in IR sensitivity & detection
- Novel techniques for materials development
- Extreme miniaturization for guidance & control
- Develop analysis of complex nonlinear systems
- Highly efficient new polymers & composites
- Energy-dense compact power & nano-actuators

10

750
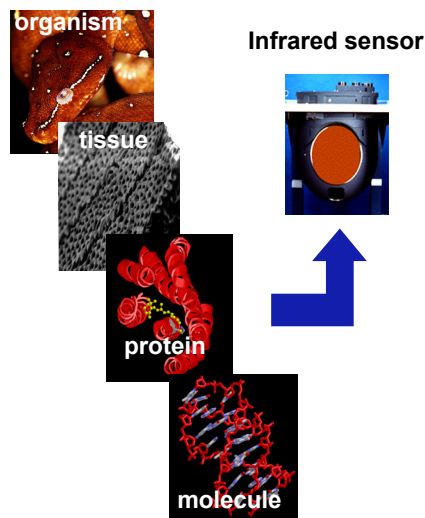
DRAGONFLY STATION KEEPING AND ALTITUDE CONTROL
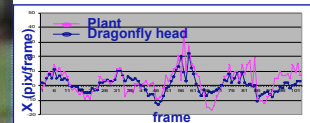
Disturbances

– **Wind**
– **Background clutter**
– **Background motion**
– **Varying light levels**

11

Akiko Mizutani: Biorobotics Laboratory, CVS, RSBS, Australian National University

DRAGONFLY PURSUIT

Akiko Mizutani: Biorobotics Laboratory, CVS, RSBS, Australian National University

DRAGONFLY PREDATION

Akiko Mizutani: Biorobotics Laboratory, CVS, RSBS, Australian National University

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MINIATURIZATION SCIENCE FOR SPACE

Objective
- Enable much lighter, more compact, microsatellite, nanosatellites & picosatellites

Approach
- Continue size/weight/power reduction efforts
- Conduct critical mass research
- Leverage investments of other agencies

Payoff
- Reduce satellite cost, weight, & size
- Improve access to space
- Increase mission flexibility

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754
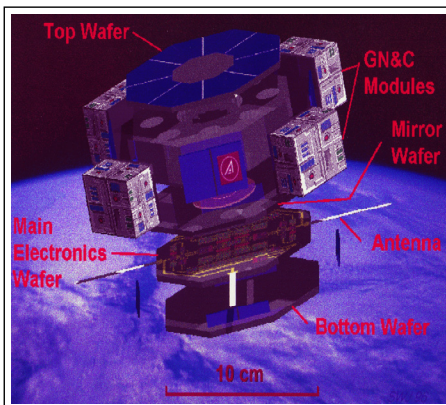
MATERIALS ENGINEERING FOR AFFORDABLE NEW SYSTEMS (MEANS)

Objective

- Exploit computational materials science and engineering to develop techniques for coupling models of material behavior
- MEANS enables materials design to be an integral part of the global design process

Approach

- Emphasize parallel design of components
- Develop computational approaches to minimize testing
- Establish applications-oriented performance objectives

Payoff

- Optimal utilization of materials and processes to produce affordable, reliable and durable products for military and civilian applications

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The Vision

- **The periodic table is the ultimate data base**

- **Imagine a design space that extends from the periodic table to input into current design software.**

- **What do we need to do to fill the gaps in this space?**
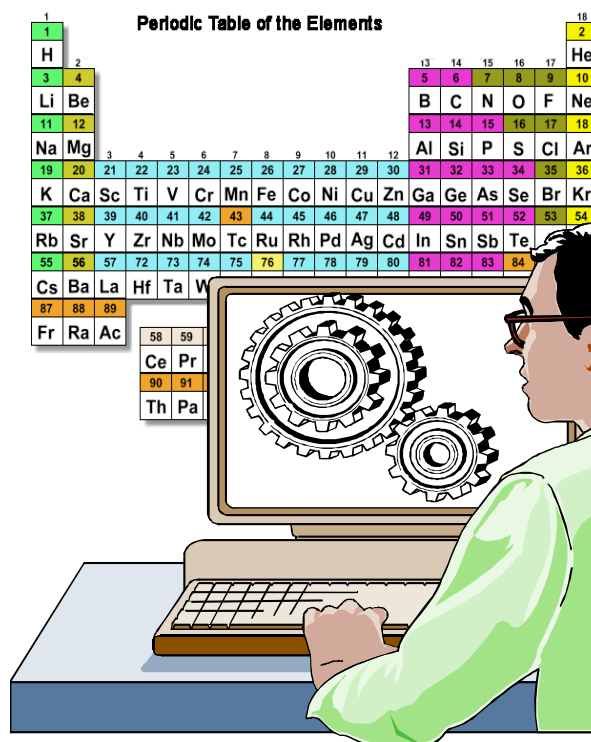
Interactions with MEANS Projects and Internal Lab Task in Alloy Design

Computational Tools for Alloy Design

**Hierarchy of Design Tools
(Olson, Northwestern Univ.)**
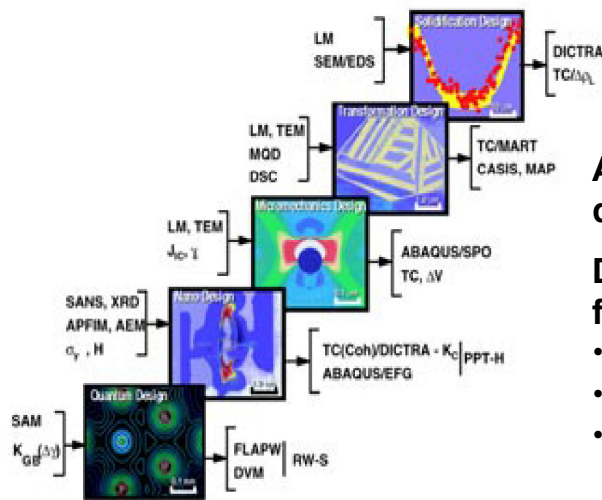
Atomic level thermodynamic quantities (Woodward, AFRL)

Developing computational tools for predicting:
· **Solid solution strengthening**
· **Phase stability**
· **Relative diffusion rates as a function of alloy chemistry (Mishin, George Mason Univ.)**

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nature
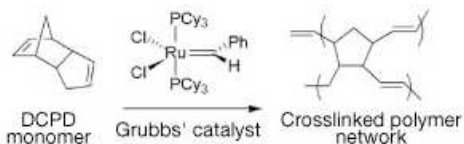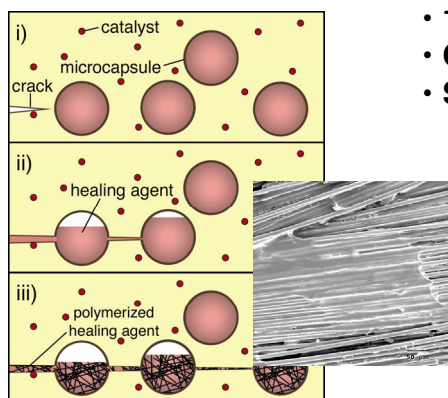
Goals:
- **100% recovery of mechanical integrity**
- **Continuous healing over lifetime**
- **Seamless integration in material structure**
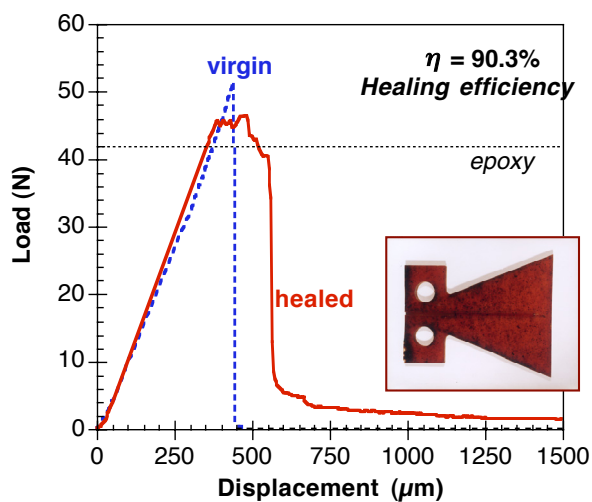
The first evidence of self-healing in quantitative terms

Univ of Illinois – Scott White [18]

GREATER UNDERSTANDING OF AEROELASTIC PHENOMENA

Ventral fins

There are around 1500 different combinations of stores for the F-16.

USAF Photo

www.f-16.net

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GREATER UNDERSTANDING OF AEROELASTIC PHENOMENA

- Aeroelastic instabilities are a real, persistent, problem.
- The motion is asymmetric.

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SUMMARY

- **AFOSR Focuses** the Scientific Community on Air Force Warfighter Needs

- **AFOSR Researches** Foundation Technologies for Critical Air Force Systems

- **AFOSR Forges** Transitions of Innovative Technologies

- **AFOSR Earns** its Reputation as "World-Class" through Early and Accurate Selection of Premiere Research Scientists

Creating Revolutionary Scientific Breakthroughs for the Air Force

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PREVIEW OF NEW: UPDATE 2004
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Dale Palmgren

19th Annual
National Educators Workshop
NEW: Update 2004

October 17 – 20, 2004
Arizona State University
Tempe Arizona
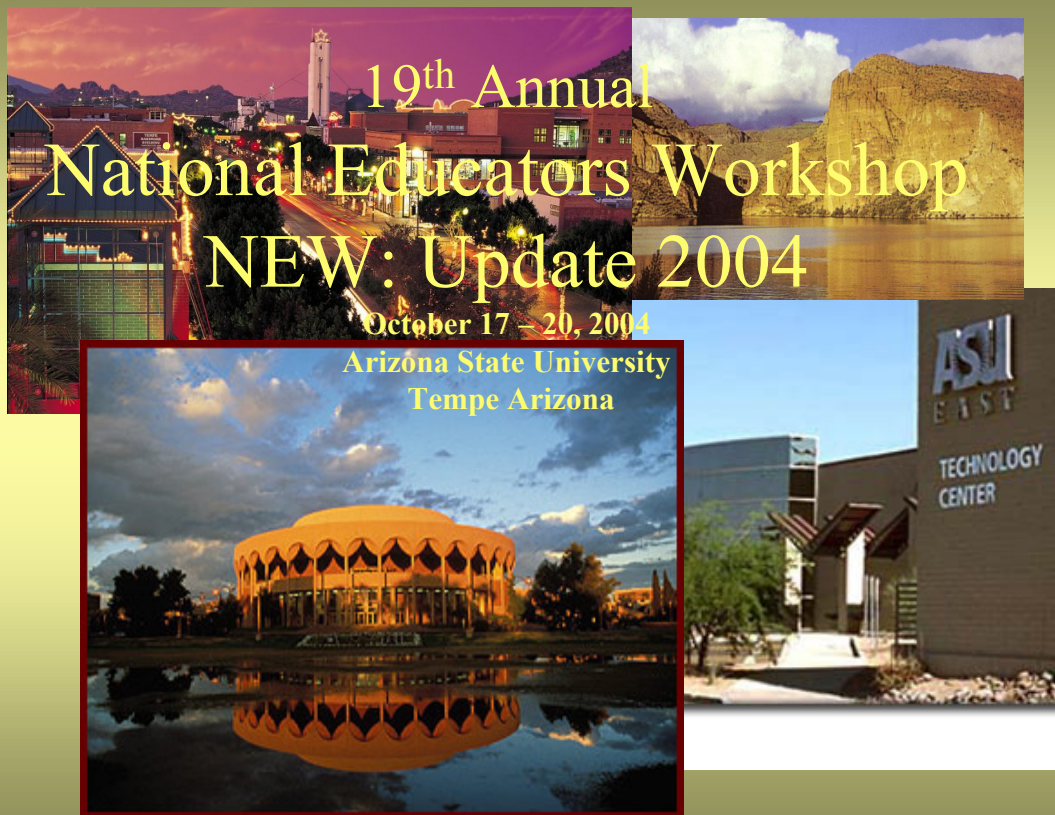
Arizona State University

- **College of Technology and Applied Sciences**
- **Department of Mechanical and Manufacturing Engineering Technology**
  - **Mesa, Arizona**

- **College of Engineering and Applied Sciences**
- **Department of Chemical and Materials Engineering**
  - **Tempe, Arizona**

Memorial Union

ASU Laboratory Tours
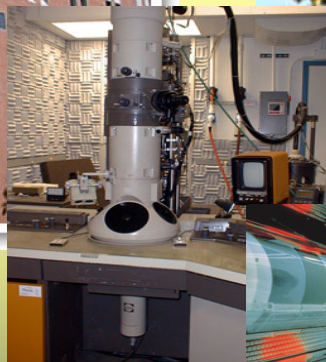
Local Industry Tours

Concurrent Technical Sessions

Arizona in October!!!!

Arizona in October!!!!

Biosphere 2

Taliesin West

Arizona in October!!!!

Sedona Arizona

Twin Palms Hotel

Sky Harbor Airport

THE VIRGINIA MIDDLE SCHOOL ENGINEERING EDUCATION INITIATIVE: TEACHING ENGINEERING IN THE MIDDLE SCHOOLS
Larry G. Richards

Director of the Center for Computer Aided Engineering
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P. O. Box 400746
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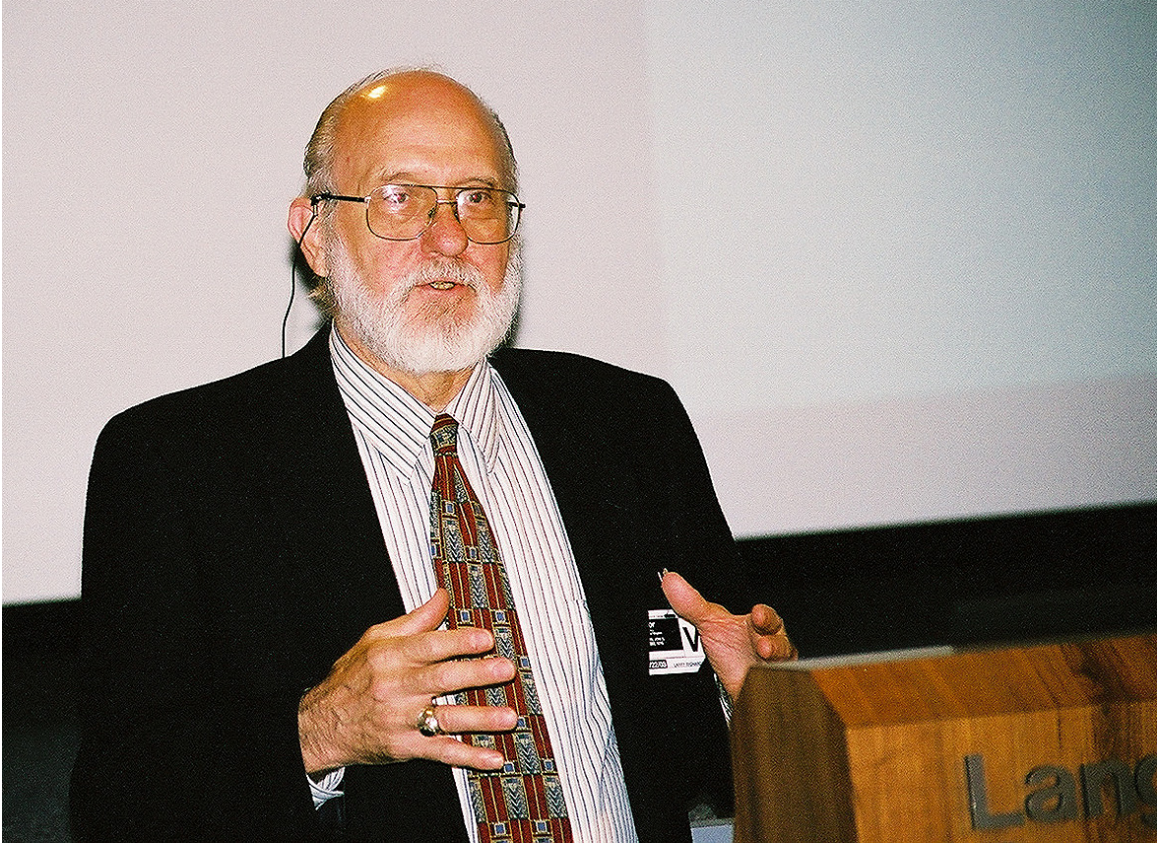
Larry G. Richards

The Virginia Middle School Engineering Education Initiative: Designing Engineering Teaching Kits (ETKs) for Middle Schools

National Educators' Workshop
October 19-22, 2003

Larry G. Richards, Hilary Bart-Smith, Gabriel Laufer,
Ioannis Chasiotis and Joseph A.C. Humphrey
University of Virginia, Mechanical and Aerospace Engineering,
122 Engineer's Way, Charlottesville, Va. 22904 - 4746

Key Words: Engineering Teaching Kits, K-12 Engineering Education, Engineering Design, Middle School Science and Math instruction, Solar Cars, Submersible Vehicles, Brain tumors and Surgery

Prerequisite Knowledge: Minimal: basic math and logical reasoning skills.

Objective: To develop, implement, test, and distribute Engineering Teaching Kits (ETKs) to introduce the engineering design approach to problem solving into middle school science and mathematics classes.

Equipment and Materials: Varies by ETK

Solar Car ETK
1. Solar cells
2. Small motors
3. Lego car bodies
4. Tires
5. Sand paper, tape, wax paper
6. Halogen lamps
7. Lux meter
8. Multimeters
9. Weights, scales

Submersible Vehicles
1. Plastic water bottles
2. Submersible motors
3. Tank – aquarium
4. Filler material (sand, marbles, pebbles, water, honey, …)
5. Cork, foam, plastic, rubber
6. Scales, and spring scales
7. Cylinders
8. Stop watches

Brainiacs
1. Brain molds
2. Jello
3. Styrofoam
4. Syringes
5. Acetone
6. Toothpicks
7. Fishing wire

Introduction

The University of Virginia has undertaken a major project to design, implement, test, and distribute Engineering Teaching Kits (ETKs) for use in middle school science and math courses. A new senior design course sequence for fourth year Mechanical Engineers allowed over 30 students to participate in this project. Six ETKs are currently being developed: submersible vehicles, gels and brain perfusion, simple machines, solar car design, design for sustainability, and engineering materials. Each will emphasize the engineering design approach to problem solving. Every team has a faculty advisor from Engineering, a representative from the Education School, and a middle school teacher providing advice and assistance.

What is unique about an ETK?

Our engineering teaching kits are being modeled and developed along the lines of the well proven, carefully evaluated and highly successful science kits developed by the SEPUP program for enhancing science instruction nationwide in the middle schools. The SEPUP kits enhance science instruction by focusing on scientific issues with significant social and/or environmental impact [1].

ETKs involve topics from science and technology that have interesting engineering applications. We are building on and complementing the science and mathematics curriculum in order to advance the engineering design approach to problem solving. Design is the essence of engineering. Although engineers engage in various other activities, it is the design activity that sets them apart from other professionals, such as physicists or chemists. The engineering design process includes at least 5 steps [2]: (a) problem definition, (b) invention, (c) analysis, (d) decision, and (e) implementation. Middle school students will learn about the essential engineering functions: design, build, analyze, test, and measure. ETKs will also include real-world constraints: budget, cost, time, risk, reliability, safety; and meeting customer needs and demands.

Each ETK will include a *student guide* explaining key concepts and methods, a *teacher's guide*, plans for demonstrations and experiments, and, where appropriate, a computer-based component (a simulation or demonstration). Most ETKs will include a design component; some will involve a contest or competition. The ETKs will conform to a standard format, and undergo a uniform set of tests and evaluations.

ETKs are being designed according to the best pedagogical principles [3, 4]. They involve active, cooperative learning. The students work in teams to solve problems and design products. The middle school students reflect on what they have learned, and explore the impacts or consequences of technology. These materials promote social, ethical, aesthetic, and environmental awareness. Finally, ETKs will promote the development of communication and presentation skills among middle school students, including information gathering and evaluation, data analysis and representation, reporting and documenting observations and results, and assessing assumptions and preconceptions.

Currently Available ETKs:

Three ETKs have already been tested in middle schools:

Submersible vehicles: This team has developed lesson plans to introduce the concepts of density, mass, volume, buoyancy, drag propulsion, and materials. Students initially experiment with different objects to determine why they float or sink. They then explore the concepts of buoyant force, drag, and propulsion. Finally, given a variety of materials and components, teams of middle school students design their own underwater vehicles. Each group separately tests their final vehicle and evaluates its performance. Finally, they document how each concept in the lesson plans influenced the design of their submarine.

Solar car design Using predetermined supplies, teams design and build an electric model car powered by energy derived from light. Students learn the basic concepts and principles of mechanical and electrical energy including how to measure each and how to relate one to the other. They also learn the fundamental principles of statics and dynamics (friction, drag, acceleration, constant velocity motion). Based on this knowledge, student teams design cars, assess their performance, and predict their power needs. They also test solar panels, compare the results to the estimated power needs of their cars, and determine the parameters for the design of their cars. They modify their designs as needed and build preliminary models. Then they test to confirm their estimates and refine the design. The goal is to build a "race-quality" car and compete with other teams.

Brain tumor perfusion: This ETK introduces students to the biological, chemical, mechanical, and medical aspects of perfusion/infusion brain tumor treatment. Student teams investigate the nature and treatment for this type of tumor, and devise a treatment plan based on their research. Physical models of the brain and the use of a mechanical syringe simulate the treatment (by infusing fluids into a tumor). The students analyze the resulting data and visualize the results. They then assess the success or failure of their treatment.

Three other ETKs are well along in their development:

Simple machines. This ETK is a set of interrelated experiments involving simple machines (levers, pulleys, inclined plane, wheel and axle). The goal is to introduce general physics and design concepts. The instructional basis of the ETK will be

781

engineering principles such as force balances, mechanical advantage, and conservation of energy. When the students understand the functions of simple machines, they will execute a series of design projects using this knowledge.

Design for sustainability: This ETK is focused on sustainability as an essential consideration in design. The materials will explore the life cycle of everyday objects (such as a cereal box), and examine the production processes and the eventual disposal of the product. The ETK will lead students to address a variety of issues, and assess the potential for redesign, recycling, and reuse.

Engineering Materials: This ETK involves engineering materials and structures. Ioannis Chasiotis has described it in another paper at this conference.

Evaluation and Field-testing

At each stage of development of an ETK, it is reviewed and critiqued by Education and Engineering faculty members, students, and middle-school teachers. When the middle school teachers think it is ready, the ETK is tried with middle school students – either in the classroom or a less formal environment. The reactions of these students to the ETK are obtained – both through observing the students using it and asking them for their opinions. Do the ETKs hold the student's interest? Are they exciting? And are the students learning what the ETK was designed to teach?

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THE USE OF ELECTROCHEMISTRY TO STUDY MATERIALS
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Electrochemistry in the Study of Materials

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Key Words: Electrochemistry, electrolysis, electrochemical cell

Prerequisite knowledge: Basic knowledge of chemistry

Objective: To use an electrolytic cell with properly treated electrodes to estimate Avogadro's number and Faraday's constant.

Equipment and Materials:

1. Power supply
2. alligator clips
3. metal strips
4. salt solutions of metals used, weak organic acid solution
5. analytical balance

Introduction:

There are many examples of electrolytic experiments in the literature (1,2,3). Many of these procedures suffer from poor adhesion of the electroplated material to the electrodes. In most of these cases the mass of metal deposited cannot be accurately determined so there are large errors in subsequent calculations. The procedure described here improves upon these methods, [especially the method from reference (4)] by shaping and pre-treating the electrode surface. In the case of zinc metal in a zinc chloride solution, the reaction

$$Zn(s) \ \text{------------------}\rightarrow \ Zn^{+2} \ (aq) \ + \ 2e^-$$
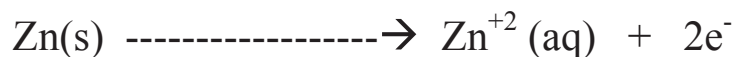
occurs at the anode and

$$Zn^{+2} \ (aq) \ + \ 2e^- \ \text{----------------}\rightarrow \ Zn \ (s)$$

occurs at the cathode (electroplating). The latter reaction is the one studied in this exercise. The zinc cathode usually contains areas of potential mechanical stress where the strip or wire was cut or bent, or has sharp edges, etc. These areas may have a electric field different that the rest of the surface frequently resulting in long irregular strands of metal being deposited at these locations, adversely affecting the uniform deposition of metal needed for accurate analysis. This problem can be reduced by removing as many stress points as possible (rounding corners, using different shape electrodes, etc) and by gently treating (no abrasives) the electrode surface with a weak organic acid and lightly polishing. We have found that is the electrode to be coated is briefly treated as the anode, this greatly reduces the formation of the long fibers and results in the acquisition of very good data.

Procedure:

An electrochemical cell is set up with a power supply and 2 electrodes in a salt solution of the metal to be plated. The eventual cathode is pre-weighed and the cell is run briefly at 100 mA for 5 minutes and then the leads reversed. See Table I for conditions and results. The mass of plated material can be calculated from the difference in the initial and final mass of the electrode. The electric charge, Q , can be calculated using the formula:

$Q = I \times t$ where I is the current and T= time

Avogadro's number (N) can be calculated using:

$$N = \frac{(Q \text{ in C}) \times (M \text{ in g/mole})}{(N \text{ in electrons/atom}) \times (m \text{ in g}) \times (Qe \text{ in C/electron})}$$

where M = the atomic mass of the metal, n = the number of electrons transferred, m = plated mass of metal in grams, Qe = the charge on the electron.

Faraday's constant (F) can be calculated by:

$$F = \frac{(Q \text{ in C}) \times (M \text{ in g/mole})}{(n \text{ in mole electron/mole Zn}) \times (m \text{ in g})}$$

Comments:

This exercise shows how a metal can be quantitatively plated on an a cathode surface during electrolysis and the data used to calculate Avogadro's number and Faraday's constant. We were much less successful at trying to calculate these values by measuring the decrease in mass at the anode. This may have been due to a variety of factors including the loss of undissolved metal at the anode

Table 1

	Trial A	Trial B	Trial C
Plating time (sec)	1500	1500	1500
Charge (coulombs)	900	900	900
Mass Plated (grams)	0.3045	0.3051	0.3066
Current (Amperes)	600	600	600
Avogadro's number (x 10^{23}) (calculated)	6.032	6.020	5.971
Faraday's Constant (x 10^4) (calculated)	9.66	9.64	9.57

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Bibliography:

Dr. H. Alan Rowe is Professor and Chairman of Chemistry in the Chemistry Department at Norfolk State University. He has been chosen as Teacher of the Year at Norfolk State University and has served as a Fulbright Senior Research/Lecturer Scholar at the University of Kelaniya in Sri Lanka. He presents over 50 chemistry/science demonstration presentations a year at local schools.

FERRO-MAGNETIC MATERIALS AND TESTS
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Ferro-Magnetic Materials and Tests

National Educators' Workshop
October 19-22, 2003

Michael J. Kozak, School of Technology
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Key Words: Stainless steel, magnetism

Objective: To demonstrate the different levels of attraction of a magnet to the different types of stainless steels. The magnetism of coins of varying currencies and face value are also evaluated.

Equipment and Materials:

1. A magnet
2. Samples of the different classes of stainless steel
3. Coins of different face values and currencies

Introduction:

It is often assumed that all stainless steels have the same degree of attraction to a magnet. This is not the case. There are five basic classes of stainless steel [1]. They are classed by their microstructure and are; austenitic, ferritic, martensitic, duplex, and precipitation hardened. Austenitic stainless steels are usually not magnetic unless they have been significantly cold worked [2]. The four other types of stainless steels typically all exhibit significant attraction to a magnet.

Coins of different currencies and face values can be made of different metals. Coins from the United States are non magnetic unless they have been altered [3]. Foreign coins are sometimes magnetic, especially German ones [4]. Magnetic coins usually contain iron. Besides iron, other elements such as cobalt, nickel, and gadolinium show strong magnetic forces [5]. Coins containing these elements may also be magnetic.

Experimental Procedure:

Simply make contact with each sample individually with the magnet and note the relative pull between the magnet and sample as they are separated. Some samples will exhibit a strong attraction to the magnet, some a weak attraction and others will have no perceptible attraction at all. Note that dropping the magnet or subjecting it to extreme heat may upset its magnetic field.[6]

Comments:

Kitchen appliances or utensils are often made of austenitic stainless steels with low magnetism so refrigerator magnets may not adhere to them. Therefore many people draw the conclusion that all stainless steels have low or no magnetism drawing from their experience with these items. However the four classes other than austenitic are magnetic as can be shown by this simple experiment. Austenitic stainless may also become magnetic if cold worked.

Coins can be made from different materials. Many coins use an inexpensive base metal that is then covered with another more expensive metal to enhance its appearance. Magnetic tests can reveal if the base or outer material is magnetic.

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Biography:

Since 1999, Professor Kozak has taught applied courses in Mechanical Engineering Technology, Industrial Engineering Technology and Computer Integrated Manufacturing Technology at Purdue University School of Technology in Richmond, Indiana. He has concentrated on courses in strength of materials, dynamics, heat transfer, thermodynamics, fluid power, industrial organization, statistical process control, and automated manufacturing.

He is a registered professional engineer in the state of Ohio, is a professional member of the American Society of Engineering Educators (ASEE) and is chair elect for the Illinois/Indiana section of ASEE. He was awarded a BSME from the University of Akron in 1982 and a MSME from the University of Cincinnati in 1986. From 1982 to 1984 he was a project engineer for B. F. Goodrich. From 1987 to 1999 he was a product development, quality, senior test, reliability, or procurement engineer for General Motors.

ENGINEERING TEACHING KIT: INTRODUCING DESIGN WITH MATERIALS TO 8TH GRADE STUDENTS

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Engineering Teaching Kit: Introducing Design with Materials to 8th Grade Students

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KEYWORDS

Materials, mechanical properties, composites, engineering design, Standards of Learning (SOL)

PREREQUISITE KNOWLEDGE

Basic knowledge of science and mathematics as determined by the Virginia Standards of Learning (SOL) requirements for 8th grade students.

OBJECTIVES

The objectives of this Engineering Teaching Kit (ETK) are: a) create a self-contained kit that will introduce middle school students to the subjects of engineering materials and design, b) guide the students through an engineering design process, c) employ the students' knowledge on mathematics and science together with new material definitions in designing a structure.

EQUIPMENT

1. Samples of composite materials (carbon fiber rods), ceramics (chalk, pottery), metals, (billet of steel or aluminum, metal sticks), polymers (polyethylene rods, styrofoam boards, straws), wood (kebob sticks), etc.
2. A balance (to measure the weight of the student project outcomes)
3. A test weight (gage whether the students met the predetermined project specifications)
4. Shape memory alloy (SMA) hinges (as lifting elements for the bridges to be constructed)
5. Styrofoam cups (for hot water to actuate the SMAs)
6. Teacher's instruction manual including student assessment materials
7. Safety goggles
8. Press breaker (can be built in house.)
9. Other instruction materials (videos, handouts, etc.)

INTRODUCTION

This project is part of a new effort in the Department of Mechanical and Aerospace Engineering at the University of Virginia (UVa) assisted by senior undergraduate students to develop ETKs for middle school students. A variety of engineering topics, ranging from submersible vehicles to solar power driven vehicles are pursued. Over 30 undergraduate students are involved divided in

teams of 5-6 students. A special course has been put in place to interface the participating undergraduate students with graduate students from UVa's school of education and middle school teachers, and also teach them the basics of K-12 education.

This ETK on engineering design and materials will be tested at local schools in the fall of 2003. By using simple materials (ceramics, metals, polymers) and their combinations (composites) 8th grade students are called to complete an engineering project, the design of a model bridge that satisfies a number of specifications.

The following are among the central specifications for this ETK:

1. It can be completed in 5 days within 45 minute class periods
2. It can be handled by a single teacher
3. It covers several of the required Standards of Learning (SOL) for the students' grade level
4. It is based mostly on demonstrations and it introduces knowledge on a "need-to-know" basis
5. It includes an assessment and evaluation components
6. It has a reasonable price.

PROCEDURES

This ETK will be implemented in five days of hourly contact with the students. A short lesson plan has been developed that describes the activities during each of the five forty-five minute class periods. The learning outcomes include the knowledge of the following:

1. Engineering basics
2. Characteristics of basic materials and their mechanical behavior
3. Definitions of stress, stretch (instead of the more abstract term of "strain"), and strength
4. Engineering design and optimization through trial and error.

In engineering basics we provide a description of the professional activities of today's engineers by emphasizing the differences between a professional engineer and a technician (mechanic) or a scientist. Then, the students are introduced to the material/mechanical properties of four types of materials: polymers, metals, ceramics, and composites. This is pursued via commonly encountered examples and applications of each material category. In connection with the durability and reliability of materials, the concepts of stress, stretch, and strength are demonstrated for basic materials (slender metal, plastic, and ceramic rods) with special attention given to the difference between forces and stresses. To that effect, the example of rods with different diameters and constant applied force is used. The definition of stretch is demonstrated via checkered rubber rulers where the students visualize the maximum tension and compression at the top and bottom surfaces of a bent beam. Also, a more elaborate material, a SMA, is introduced to demonstrate the existence of "materials with memory." Such examples are invaluable in the design of a bridge that the students will be called to accomplish later. This part of the ETK exposes the students to interactive learning, and it builds on teamwork and query-based teaching.

The concepts of stress and deformation are complemented by demonstrations of fracture of material samples. Commensurate to deformation and failure concepts is the introduction of specifications, constraints, and cost that provide the mathematical frame for the design procedure. The short lesson plan is detailed next.

Day 1: Engineering Basics

The students are presented with the question "how does an engineer differ from a mechanic?" and are given the opportunity to discuss their preconceived opinions and ideas. It is also important to instill understanding and appreciation for the importance of engineering to the society: a combination of short videos of modern engineering marvels and failures provides (e.g. the Tacoma Narrows Bridge) the basis for a discussion. Questions such as "what went wrong" and "how could we do it better" are key in stimulating the students' interest and participation.

Next, the students are given a general outline of their capstone project for the purpose of generating questions from the students' side. This serves the purpose of better understanding their background and at the same time introducing them, early enough, to their problem, thus accomplishing a problem-based approach as all knowledge will be given to them on a "need to know" basis. The students are required to form teams of four. Team forming/building activities such as assigning a facilitator, an interface person, and a scribe are also part of the process.

The problem is presented as follows: "Build the most light-weight bridge that can lift a predetermined weight using materials form a given inventory". This provides the students with a brief opportunity to build a preliminary model and thus ensure that they understand the problem early enough. However, without the knowledge they will acquire in the following days their designs cannot match the given specifications that are set so that careful (via a design approach) combinations of materials (i.e. composites) are required. The inability to meet the specifications generates questions, which the students provide as part of their first assignment that also includes their suggestions about what is needed to accomplish their task. Their questions and suggestions are discussed in the beginning of the second period. This process gives them a perspective about the material they are introduced to and helps them integrate all new knowledge in a creative manner in their final project.

Early on day one the students are also advised that on the fourth day a quiz will be given to them to examine their proficiency in the concepts they will learn and that it this quiz will be used to evaluate their performance and individual accountability as team members.

Day 2 and 3: Materials characteristics and definitions

Days two and three constitute the instructional phase. The basics ideas about materials selection and properties are conveyed using demonstrations and experiments to accomplish the following:

1. Teach the basic considerations during materials selection about materials failure
2. Demonstrate the differences between brittle and ductile materials
3. Demonstrate the differences between elastic and plastic deformation
4. Be able to select materials based on previous points (1-3)

The main focus in these two days is a fracture lab consisting of four stations, one for each of the primary materials. At each station, there are a variety of different specimens for demonstration or testing. The students conduct bending tests and use the simple bending equation to predict their observations. A press breaker offers a mechanism by which various specimens can be safely fractured. The design allows the students to continually apply a known point load to specimens while observing their deflection until failure. Key highlights:

- Specimens are clamped on either side of the machine preventing hazardous projectile discharge upon failure. These clamps also allow the accommodation of a variety of specimen lengths and cross-sections. Safety goggles are required.
- The load is imposed by a spring attached to a screw of a known spring constant. The measurement of changes in spring length allows determining the load on the specimen.
- A ruler mounted behind the specimen can examine its deflection, permitting distinction between brittle and ductile materials.

This breaker provides the students with "hands-on" experience in material failure. These experiments are directed so that the students understand that monolithic materials cannot satisfy the needs of modern structures for light-weight, strength, durability, and flexibility and that material combinations merge a variety of properties in one material. Naturally, the following question is posed: *"How can I construct a material that has the flexibility of a polymer, the strength of a ceramic, and still maintain the weight of a polymer foam?"* The students are pointed to commonly designed fiber, particle, ply, sandwich, honeycomb, and other cellular composites that demonstrate these advantages.

Fiber-reinforced composites are specifically emphasized because they are the cornerstone of the final project. The elementary relationship that provides the composite material stiffness as a function of the stiffnesses of the matrix and the reinforcement is provided to expose the students to mathematical design tools, while the costs of individual components and their weight are made available so that the students can (on days 4 and 5) create weight and cost functions and optimize their bridge structures based on a trial and error approach. To connect structural design with service load, the proper distribution of fibers with respect to an applied force is demonstrated and the students are called to explain the roles of the reinforcement and the matrix. Special emphasis is given to the superior strength and low weight of composite structures as compared to the properties of the original components, as well as the significantly higher cost of composite materials that is disproportional to the cost of their simple components.

Days 4 and 5: Project design, implementation, and testing

Days four and five are devoted to the design, building and testing of the students' bridges. At this point the idea of design constraints is introduced via the definition of their project. The capstone project is the design and implementation of a bridge based on the following description:

"The morning traffic entering Washington D.C. crosses the Potomac River. Currently the bridge has only two lanes each way and creates a bottleneck into the city. Because of this small bridge a trip that normally takes 20 minutes can take up to 2 hours during rush hour. The government will spend 50 million dollars for the construction of a new bridge that is eight lanes wide and can hold the weight of one thousand cars and trucks. The government requires that a smaller model be made before any construction begins, at the maximum cost of $1,000. This model must hold at least 10 pounds of weight and be 1 foot long. The Potomac River also sees a lot of boat traffic at night and the bridge must allow for boats to pass during off-peak hours."

These specifications eventually require that the students build their bridges out of light-weight styrofoam reinforced with wooden or metal kebob sticks inserted in the longitudinal direction to

achieve high bending stiffness and strength while maintaining low weight. The number of kebob sticks is restricted by the fictitious total cost of $1,000. The students have to incorporate the knowledge about surfaces in tension and in compression they acquired in the first days and use the reinforcing elements on the side of maximum tension rather than compression. The matrix choices are styrofoam, gel, glue, and insulating foam. The available fibers are wood kabob sticks, metal kabob sticks, and drinking straws. Each matrix or fiber has a given price per piece or volume and the students will have to maintain their budget in perspective. Moreover, shape memory alloy (SMA) hinges must be incorporated below the bridge and lift it to allow for boat traffic. The break between the fourth and the fifth day allows the students to think about their designs. All calculations for the material selection and the design of the bridges to be built are assigned as individual homework.

During the fifth day the students finish their bridges. The latter are tested via a predetermined weight and the total bridge deflection (under load), cost, and weight are assessed. The students must demonstrate a smart way of lifting their bridges and the appropriate use of the SMA hinges included in the ETK is evaluated.

COMMENTS

The described short lesson plan is currently in preparation for testing at local middle schools in Charlottesville, VA. The feedback to be collected from this procedure will be incorporated in an extended lesson plan. The group expects to complete this project by the end of the current academic year after a number of iterations at local middle schools.

It is important to outline some of the ideas and methods behind the construction of this ETK. This ETK addresses the middle school age group understanding that students develop a viewpoint about their preferred professional education at an early age. To that effect, the National Science Foundation (NSF) [1] and the National Academy of Engineering [2,3] have cautioned before that students need to gain interest in engineering at young ages, before they reach high-school, and that future technological illiteracy can be avoided only if "science teachers are provided with the background and the tools to teach technology and engineering in their classes." This lack of "engineering" education at pre-college ages has reduced the appealing of Engineering to today's children and has resulted in decreased college enrollments. Thus, new tools and methodologies need to be integrated in middle school education. In the past, Science Teaching Kits (STKs) [4,5] have been a successful approach to introduce various subjects in science to K-12 education. If Engineering Teaching Kits (ETKs) are properly implemented at the early stages of K-12 education significant impact could be achieved on students' decision making for higher education [6]. Supporting material in that regard are the numerous books [7,8,9] that make elaborate engineering concepts approachable to pre-college children by making effective use of the students' background and the local SOLs [10]. This ETK is based on modern teaching practices that advocate inquiry-based teaching and learning [11] that are expected to increase the students' enthusiasm and knowledge retention. Its potential impact is maximized by incorporating the middle school students' knowledge in mathematics and science that allows the integration of this ETK into standard middle school curricula.

BIOGRAPHY

All participating students are in their senior year in Mechanical and Aerospace Engineering at the University of Virginia. This project is supervised by Professor Ioannis Chasiotis with invaluable input by Professor Eric Maslen.

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DETERMINING PULL-OUT DEPTH OF COMPOSITE REINFORCING BARS IN CONCRETE

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Determination of Development Length
of
Composite Reinforcing Bars in Concrete

Harvey Abramowitz, Ralph E. Bennett III,
Joel Wright & Dave Boynak

Prerequisite Knowledge

The student should be familiar with:

- rebar used to reinforce concrete
- elastic modulus
- tensile testers

Objectives

- To verify published development length equation for uncoated Fiber Reinforcing Plastic (FRP) rebars.

- To determine the effects of a sand and epoxy coating on development lengths of FRP rebars.

Equipment and Supplies

- Fiber Reinforcing Plastic Rebars
- Sand
- Epoxy
- Tensile Tester
- DYNAMOE^{TM} Tester
- Facilities for Making Concrete

FRP Advantages

1. Non-corrosive

2. Non-magnetic

3. Does not conduct electricity

4. Does not conduct heat

5. Density = 1/4 that of steel rebar

6. Ultimate tensile strength approx. 100   ksi

FRP Disadvantages

1. Twice the price of deformed steel rebar
2. Cannot be field bent
3. Not easy to test or prestress (grips)
4. Limited amount of test data
5. Poor response in shear and in torsion
6. Should not be used in extremely long spans

Tensile Strength

Grips and Testing Set-Up

FRP
REBAR
+
FRP
REBAR
WITH
EPOXY
+
FRP
REBAR
WITH
EPOXY
AND
SAND
+
CONDUIT
SLEEVE
=
GRIP
ASSEMBLY

810

GRIP TESTING SET-UP IN TINIUS OLSEN

Wedge Arm

Wedges

Body of Tinius Olsen

FRP Rebar
With Epoxy and Sand
And Conduit Grip

Body of Tinius Olsen

Wedge Arm

811

GRIP TESTING SET-UP

WEDGE 1

WEDGE 2

Body of Tinius Olsen

Conduit Grip

FRP Rebar with Epoxy and Sand Coating

FRP Rebar

Front view

WEDGE 1   WEDGE 2

Bottom view

812

GRIPS

TESTING PROCEDURE

1) APPLY EPOXY AND SAND TO 7" OF FRP REBAR

2) CUT A 7" PIECE OF 1/2" OR 3/4" STEEL
   CONDUIT DOWN SIDE AND OPEN SLIGHTLY

3) SLIDE THE STEEL CONDUIT SLEEVE OVER THE
   COATED BAR

4) PLACE IN TESTING MACHINE

5) REMOVE GRIPS FROM BAR

GRIPS
ADVANTAGES

1) VERY INEXPENSIVE

2) EASY TO REMOVE AND REUSE

3) INSTALLATION AND REMOVAL TIMES WERE 1/10
   THOSE OF THE ORIGINAL GRIP

4) ABLE TO ACCOMMODATE BOTH 1/2" AND 5/8"
   DIAMETER BARS

FRP TESTED

- **SIZES**

  #4 (1/2"), #5 (5/8")

- **COMPOSITION**

  Fiberglass ("E" glass) wrapped around polyester rod with thermosetting vinyl ester resin

SAND / EPOXY COATING

- **SAND**
  - Ottawa Sand
  - -30+40 mesh
- **EPOXY**
  - DC80
  - Hardener:Resin   1:1
  - Curing Time   24 h

TENSILE STRENGTH RESULTS

SIZE	EXPERIMENTAL UTS (ksi)	SPECS UTS (ksi)	DIFF (%)
1/2 "	112.7	107.0	5
5/8 "	87.2	95.0	8

DYNAMIC MODULUS OF ELASTICITY

DETERMINED BY VIBRATION ANALYSIS USING A DYNAMOE™

Figure 7. DYNAMOE Set-up

820

822

E_d
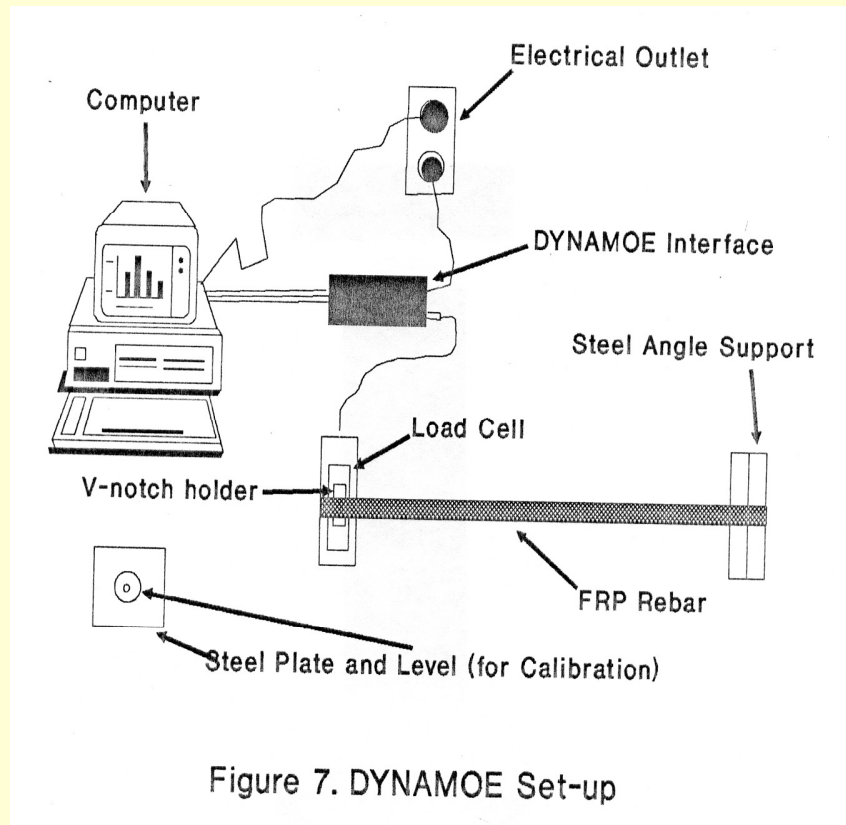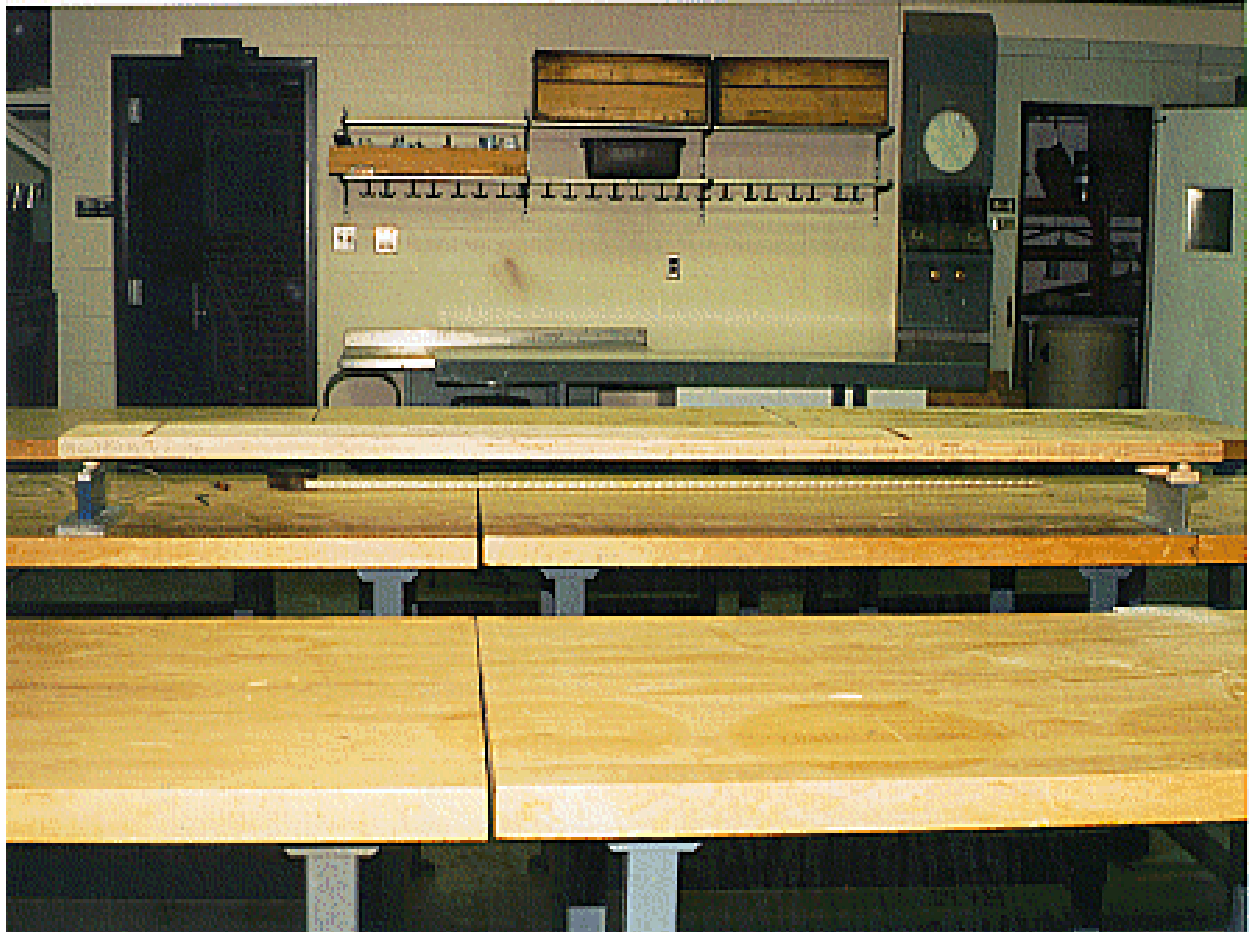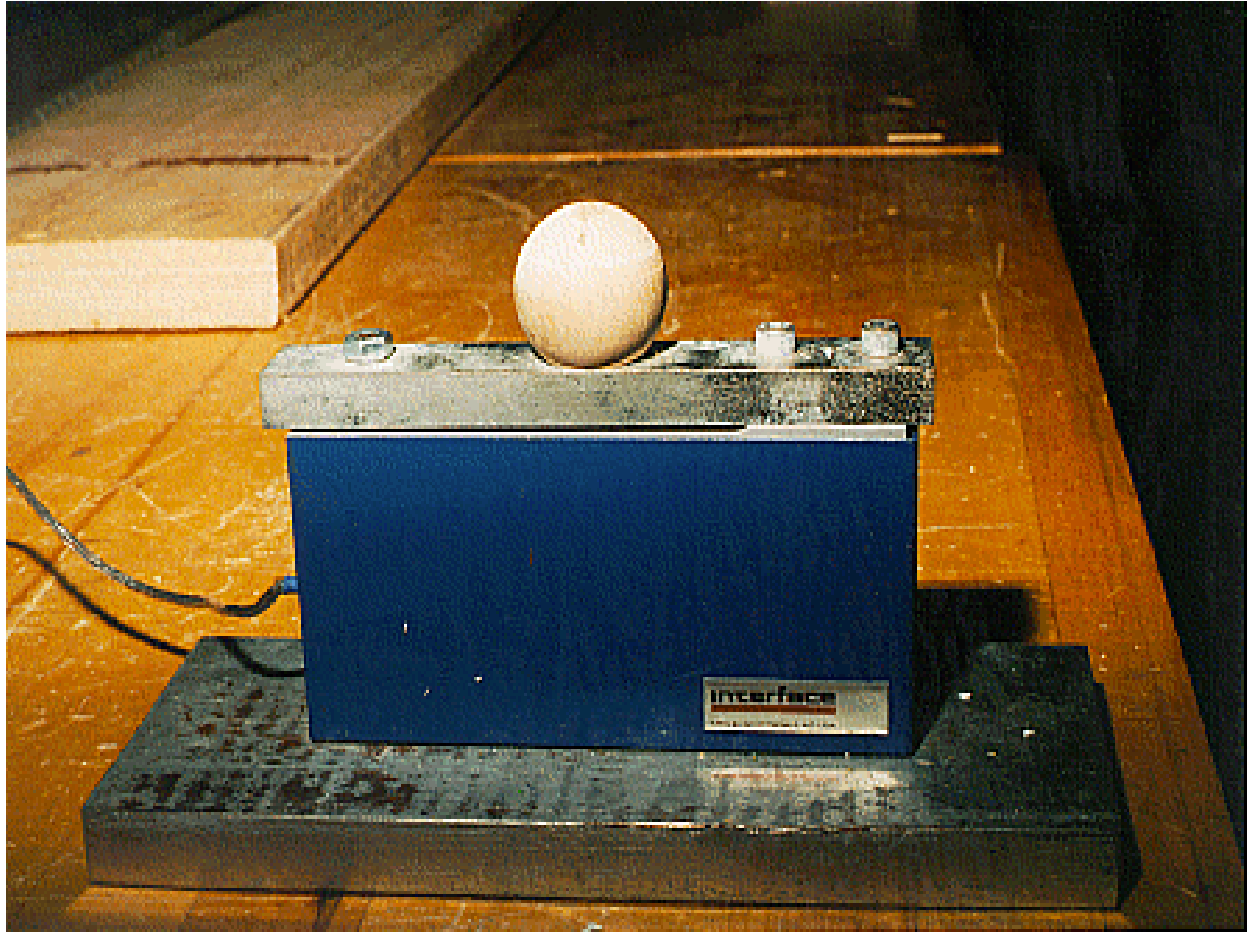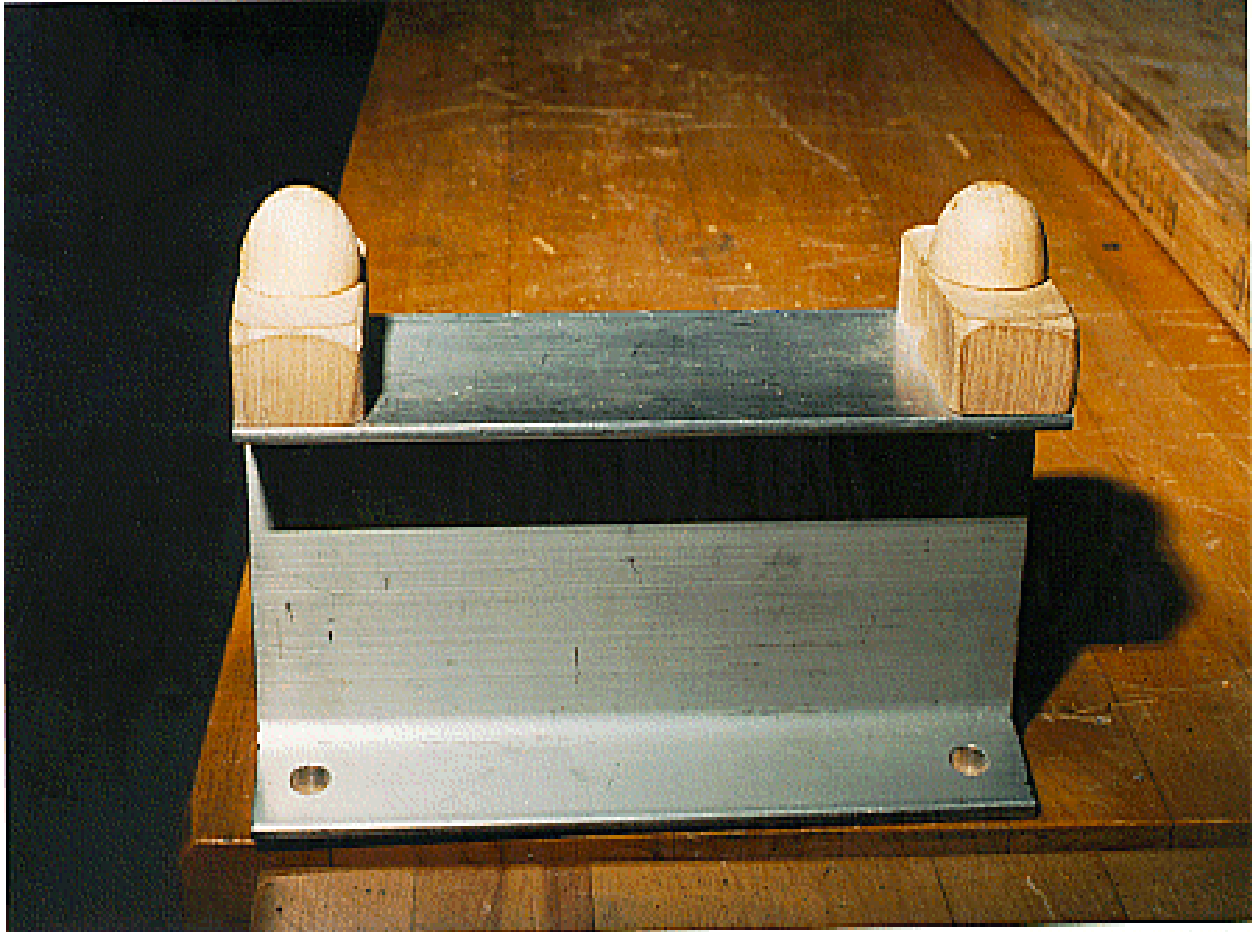
$$E_d = \frac{f^2 WL^3}{2.46gI}$$

or

$$= \frac{f^2 WS^4}{2.46gIL}$$

INPUTS

- WEIGHT

- LENGTH / SPAN

- HEIGHT / DIAMETER

- WIDTH

OUTPUTS

- DENSITIES

- f

- I

- E_d

- EI

freq dmp = 17.85 Hz   env mag = 0.76 lbs
angle = -282.0 deg   time con = 1.94 s
freq ntr = 17.85 Hz   1/log dec = 34.7

ID# = 1   E = 2.308 > 0.000 e6 psi
PASS   EI = 6.168 > 0.000 e6 lbs*in2
                 spec grav = 0.378
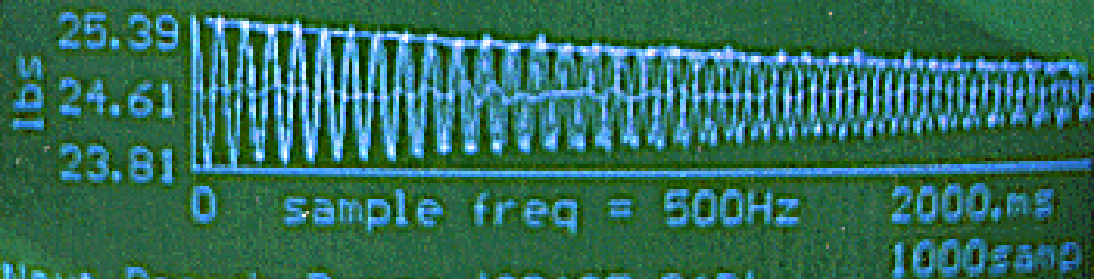
25.39
24.61
23.81
0   sample freq = 500Hz   2000.ms
                            1000samp
Next Board: Press 'SPACE BAR'
Same Board: Press 's'
Press 'm' to return to main menu

826
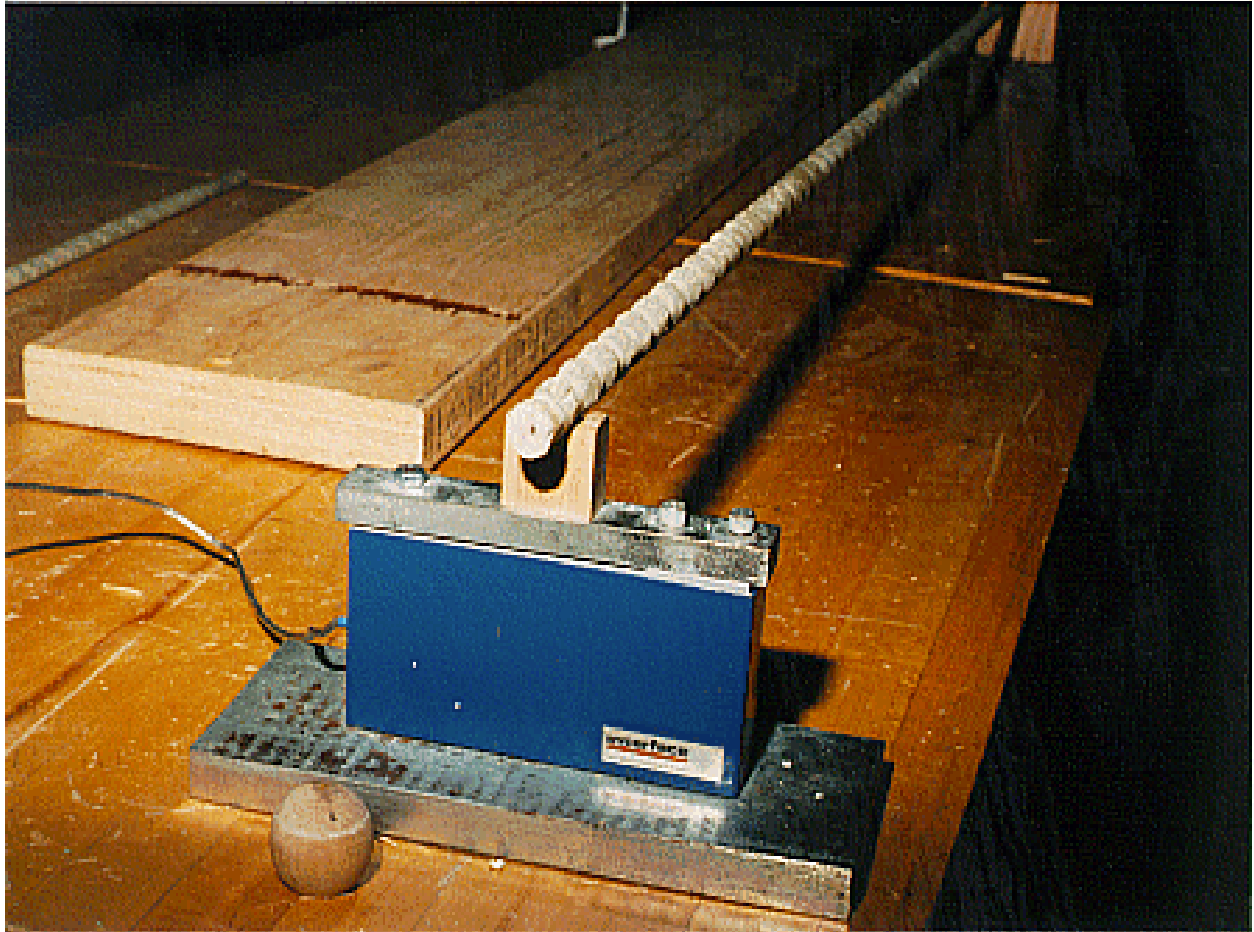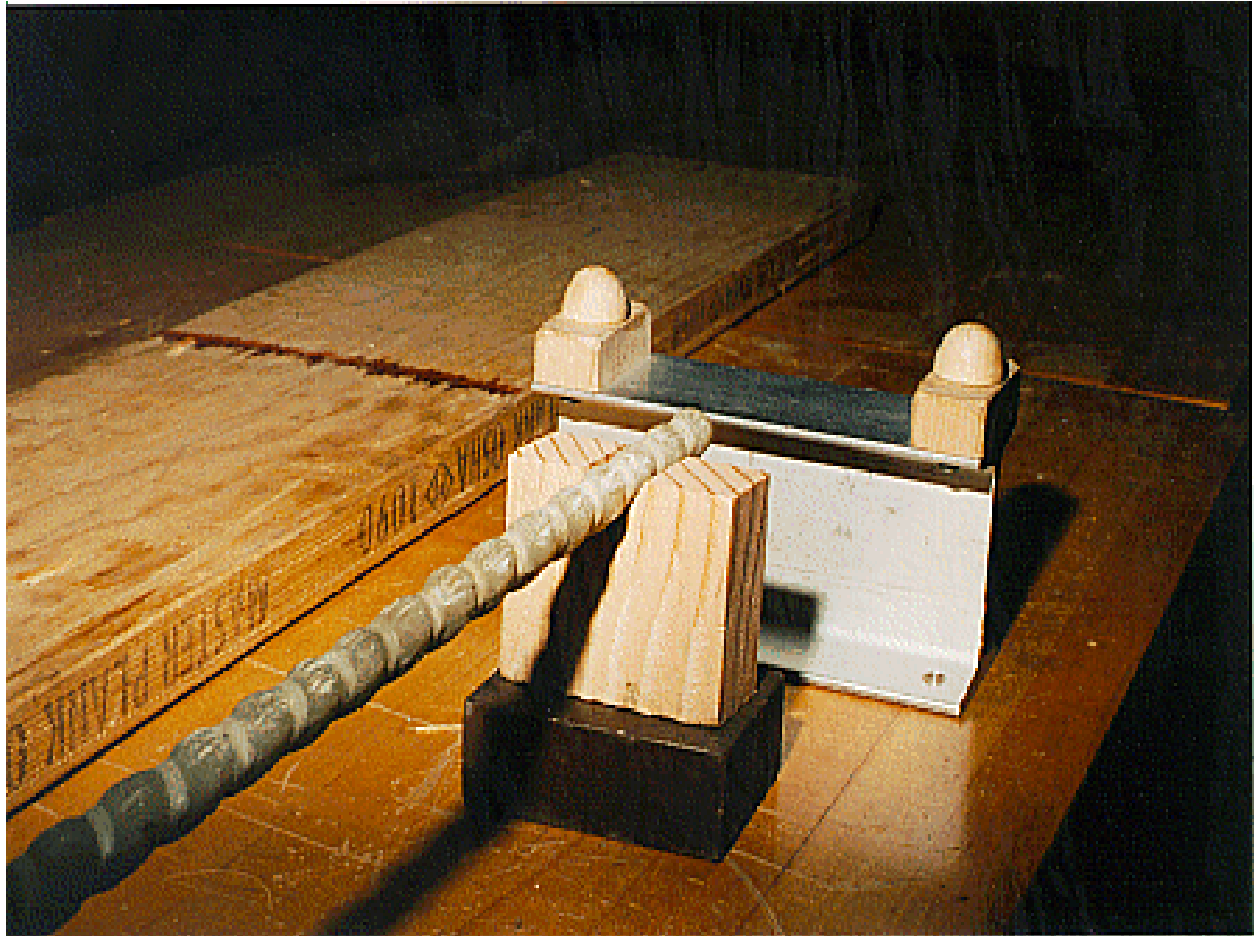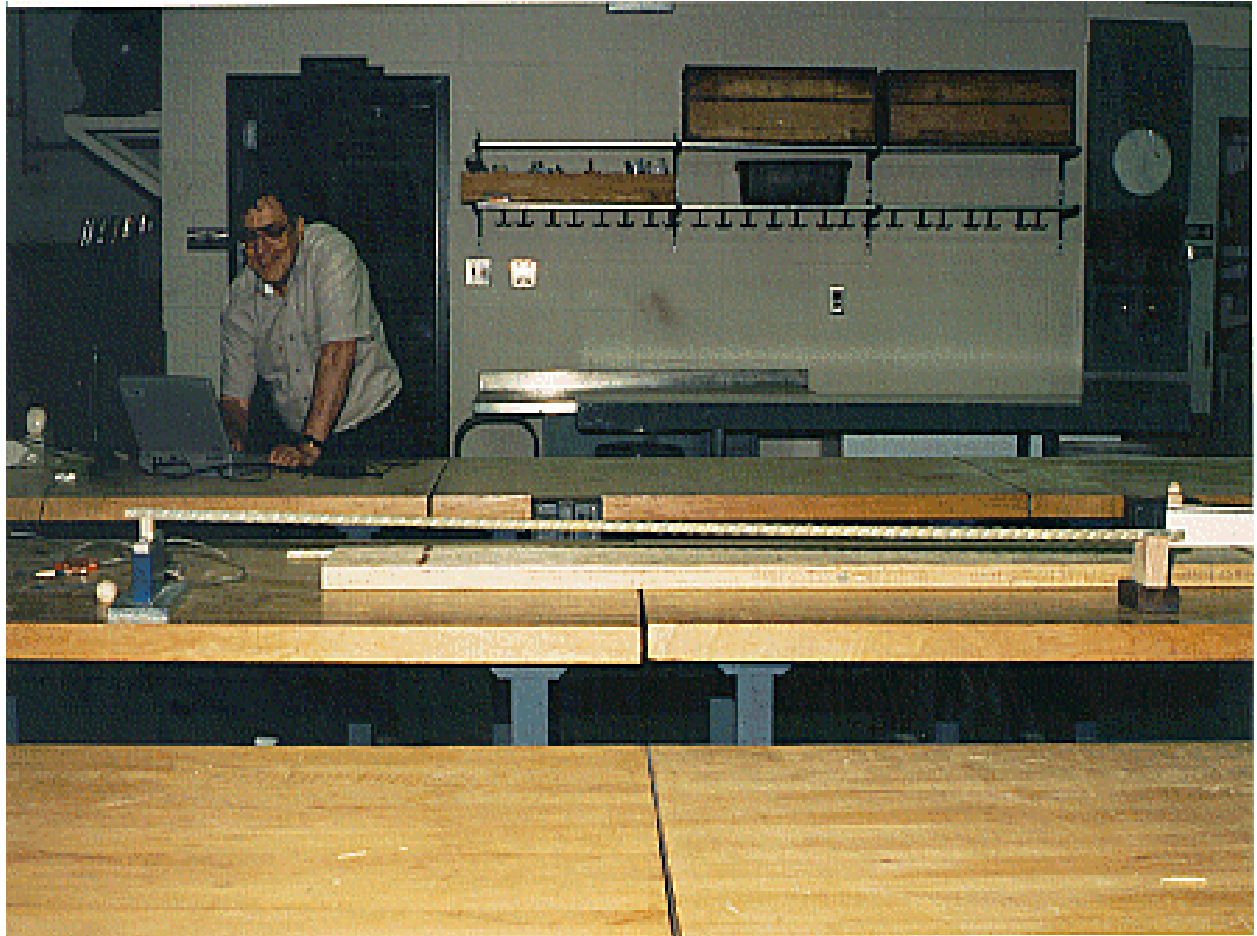
DYNAMIC MODULUS OF ELASTICITY

SIZE (in)	EXPERIMENTAL (Mpsi)	SPEC (Mpsi)	DIFF (%)
1/2	7.17	7.21	<1
5/8	6.99	7.21	3

DEVELOPMENT LENGTHS

TYPES OF FAILURE

Pull-Out Failure
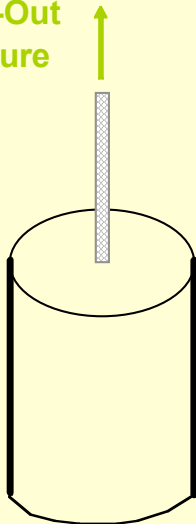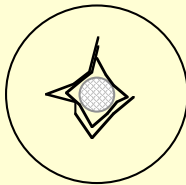
Splitting Failure
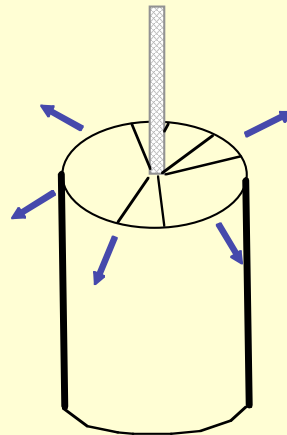
Rebar Failure

Front view

Front view

Front view

Bottom view

Bottom view

Bottom view

832

Wedge Arm

PULL-OUT TESTING SET-UP

Wedges

Body of Tinius Olsen

Concrete Specimen

FRP Rebar With Epoxy and Sand And Conduit Grip

Concrete Specimen Holder

Body of Tinius Olsen

GRIP TESTING SET-UP

Front view

Bottom view

WEDGE 1 WEDGE 2

WEDGE 1 WEDGE 2

Body of Tinius Olsen

Conduit Grip

FRP Rebar with Epoxy and Sand Coating

FRP Rebar

834

DEVELOPMENT LENGTH

1. BOND STRENGTH

  A. ADHESION BETWEEN REBAR AND CONCRETE

  B. GRIPPING FORCES DUE TO SHRINKAGE

  C. FRICTIONAL RESISTANCE TO SLIDING AND INTERLOCK

  D. DIAMETER OF REBAR

2. TENSILE STRENGTH OF REBAR

3. ULTIMATE COMPRESSIVE STRENGTH OF CONCRETE

INTERLOCKING FORCES
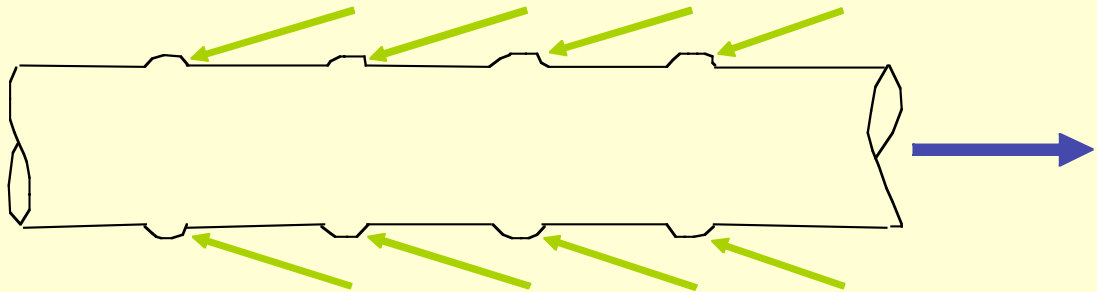
Forces on bar from concrete

INTERLOCKING FORCES
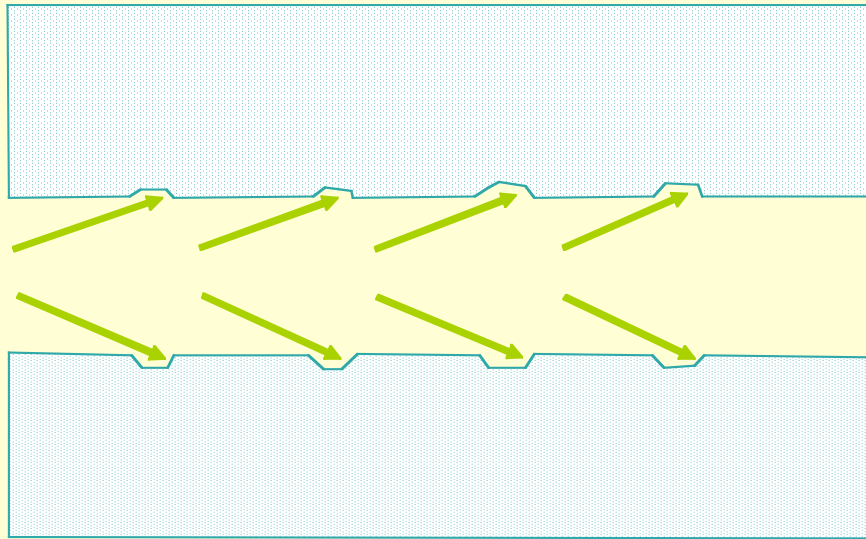
Forces on concrete from bar

Concrete Compressive Strength Test

**Compressive Force
Applied by Tinius Olsen**

**Concrete Test
Cylinder**

Middle Body of Tinius Olsen
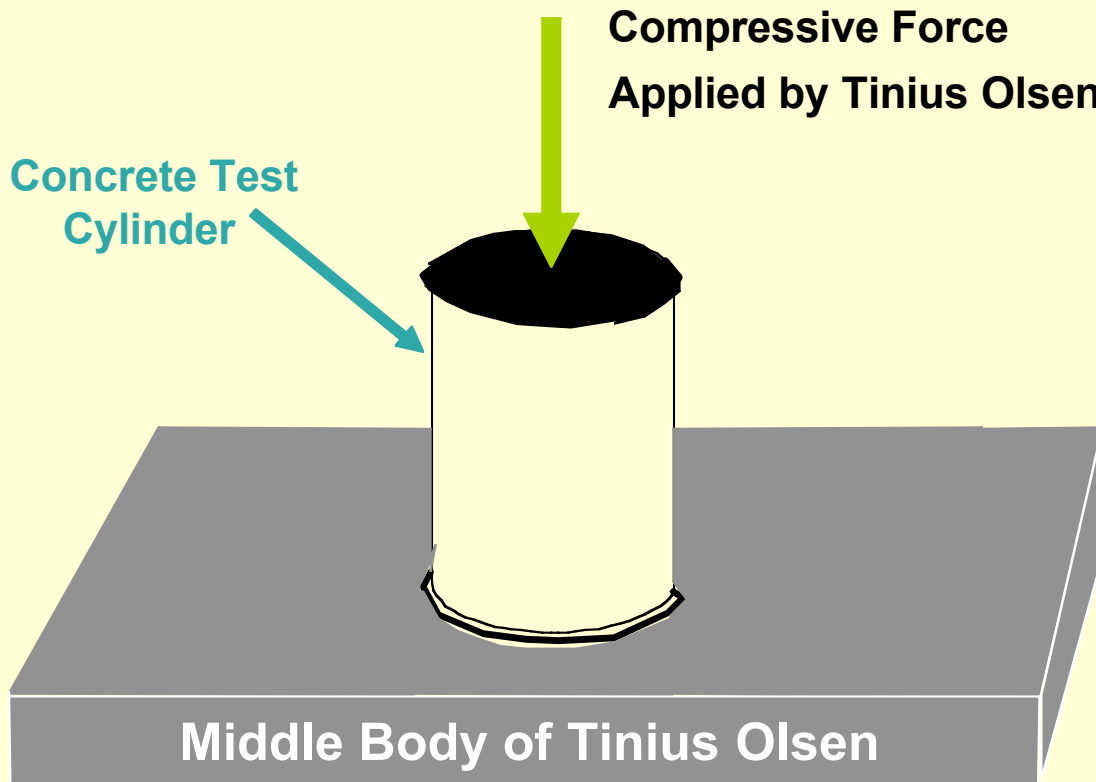
CONCRETE

- TYPE:
  - III
    - 7 DAY STRENGTH
  - NON AIR ENTRAINED

- AGGREGATE SIZE
  - FA : CA   4 : 6
  - FA   Fineness Modulus 2.7
  - CA   Max 3/4"

Concrete
Poured In

Slump

Slump
Container

Empty Slump
Container

Concrete

STEP 1

STEP 2
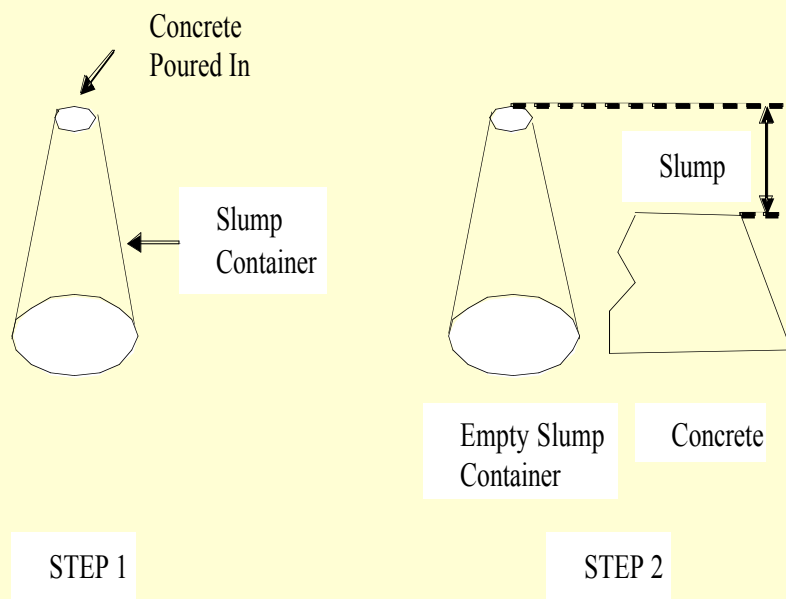
Fig. 1: Slump Test

CONCRETE (CONT)

- AGGREGATE / CEMENT RATIO   4.26 : 1

- WATER / CEMENT RATIO   1 : 2

- SLUMP   2 - 3"

- COMPRESSIVE STRENGTH   5000 psi

EMBEDMENT DEPTHS

6, 12, 18, 24 INCHES

CONCRETE FORMS

- CARDBOARD CYLINDERS

- PVC CYLINDERS

TEST MATRIX

Depth (in.) \ Type	1/2" With Sand	1/2" Without Sand	5/8" With Sand	5/8" Without Sand	Total
6	5	5	5	5	20
12	5	5	5	5	20
18	5	5	5	5	20
24	5	5	5	5	20

PULL-OUT TESTING PROCEDURE

1. DETERMINE BATCH PROPORTIONS

2. MIX INGREDIENTS FOR CONCRETE

3. POUR CONCRETE INTO TEST SPECIMENS

4. PLACE TEST SPECIMENS IN HUMIDITY ROOM

5. REMOVE CARDBOARD TUBING FROM CONCRETE

6. PLACE SPECIMENS IN PVC PIPE

7. TEST PULL-OUT DEPTH

DEVELOPMENT LENGTH

EQUATION:

$$L_d = \frac{f_{ULT} \cdot A_b}{C \cdot \sqrt{f'_c}}$$

DEVELOPMENT LENGTH

PLEIMANN EQUATION:

$$L_d = \frac{f_{ULT} \cdot A_b}{20 \cdot \sqrt{f_c'}}$$
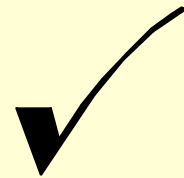
EPOXY / SAND RESULTS

SIZE	1/2 (IN)		5/8 (IN)	
SAND	YES	NO	YES	NO
C	17.62	14.91	27.81	24.32
DIFF (%)	15		13	

SUMMARY

- GRIP AND FIXTURE ASSEMBLY
  DESIGNED THAT ALLOWS FOR
  DETERMINATION OF UTS AND
  DEVELOPMENT LENGTHS OF FRP
  REBARS

- DYNAMIC MODULUS OF ELASTICITY
  DETERMINED USING THE DYNAMO^{TM}

SUMMARY (CONT)

- DEVELOPMENT LENGTH EQUATION FOR UNCOATED BARS VERIFIED

- SAND EPOXY COATING REDUCED DEVELOPMENT LENGTH BY 10%

THE IMPACT OF INTERFACIAL ADHESION ON THE STRAIN-TO-FAILURE OF CLAY/EPOXY NANOCOMPOSITES

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The impact of interfacial adhesion on the strain-to-failure of clay/epoxy nanocomposites

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Abstract

In this paper a simple methodology is present for detecting the onset of debonding in clay based nanocomposites. The procedure is based on the constant illumination of the test specimen as it is subjected to tensile deformation by sequential step-strains. After each step-strain, an image of the specimen is taken along its gauge length using a digital camera, with the image being stored in the computer for later analysis using image analysis software. Test results from a nanocomposite containing a weak interface between the clay and matrix indicates that interface debonding begins to occur above 1 % strain, as evidenced by a reduction in the transmitted light through the specimen with increasing strain. Based on related research, the darkening of the specimen was interpreted as clay-matrix debonding. In contrast to the approximately 11 % failure strain of the base epoxy resin, the nanocomposite specimen with the weak interface failed at 3.6 % strain.

Using the surface treatment technology advanced in the development of nylon-clay nanocomposites, interfacial adhesion between the clay and matrix was achieved through the establishment of covalent bonds between the acid groups on the treated clay surface and the epoxide group of the resin. As a result, the darkening of the specimen above 1 % strain was suppressed. However, the strain-to-failure of this strong interface clay nanocomposite was less than the weak interface nanocomposite (approximately 1.6 % strain). The incomplete exfoliation of the clay and non-optimized curing between the clay platelets are believed to be responsible for this reduction in failure strain.

KEYWORDS: Nanocomposite, Failure Analysis, Montmorillonite, Debonding

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1   Introduction

It is generally known that an essential characteristic of a fibrous reinforced material is the ability of the matrix to transmit loads to the reinforcement by shear. If this ability does not exist, the reinforcement can slide freely within the matrix and will contribute little to the strength and stiffness of the composite. In addition, poor adhesion, when the reinforcement is subjected to off-axis loading, contributes to premature failure and poor durability of the composite [1]. Research results on clay nanocomposites prepared from polyurethane [2,3] and elastomeric epoxy [4] resins show that the tensile strength, tensile modulus and strain-to-failure of these nanocomposites are increased relative to the neat matrices. Since the clay is treated with an alkyl ammonium salt to facilitate exfoliation, this "trifecta" is achieved without the formal establishment of significant adhesive forces between the nanomaterial and the matrix. Therefore the improvement in engineering performance properties with a poor adhesive interface contrasts the behavior typically observed in fibrous composites and appears to fulfill the promise envisioned by early researchers, of using nanotechnology to achieve significant increases in materials performance.

However, similar results on glassy epoxies [5-7], which are often used in structural composites, indicate that, like fibrous composites, modulus and strength increases in the nanocomposite are achieved at the expense of its strain-to-failure. In addition, research on TPO (thermoplastic) nanocomposites (see Figure 1) targeted for semi-structural automotive applications exhibit a similar reduction in the strain-to-failure with nanoclay inclusion [8]. These mixed results and the results from other researchers indicate a more complicated set of factors influencing the interaction between the matrix and nanomaterial. They may include the adhesive strength of the nanomaterial/matrix interface; the intrinsic toughness of the host matrix; the dispersion of the nanomaterial within the matrix; and the size, shape, and exchange capacity of the nanomaterial.
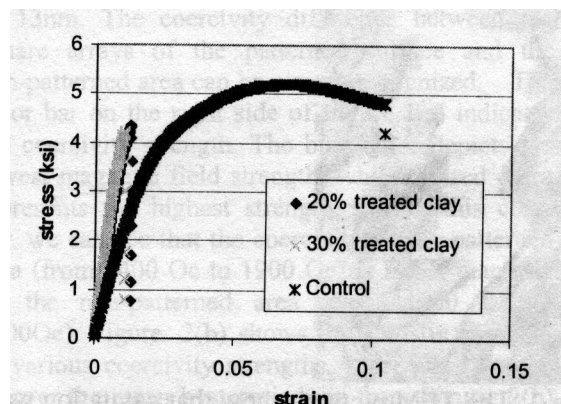
Figure 1. The stress-strain curves of polypropylene clay hybrid (PPCH) nanocomposites. The control sample contains 10 % mass fraction of montmorillonite clay. (*taken from* [8])

To better understand the dynamics of these interactions, test methodologies that detect and quantify the onset of failure and the nucleation of critical flaws in nanocomposite materials are needed. In this paper, the responses of clay nanocomposites that contain strong and weak interfaces are monitored using optical imaging technology as the test specimens are subjected to tensile loads. The interfacial strength of the clay/matrix interface is altered at the molecular level by changing the amine additive used to treat the clay. The manner in which optical imaging is used to detect the onset of clay matrix debonding is discussed.

2   EXPERIMENTAL

2.1   Materials*.

Sodium montmorillonite (Na$^+$ Cloisite$^®$) and montmorillonite treated with dimethyl, benzyl, hydrogenatedtallow quaternary ammonium (Cloisite$^®$ 10A) were obtained from Southern Clay Products, Inc. The diglycidyl ether of 1,4-butanediol (CAS # 2425-79-8; trade name: Araldite RD-2; common name: DGEBD) and 1,3-phenylenediamine (CAS # 108-45-2) were obtained from Aldrich-Sigma Corporation. For 12-Aminolauric-acid (CAS # 693-57-2), TCI America was utilized as a resource. Many suppliers produce the diglycidyl ether of bisphenol-A (CAS # 25068-38-6; common name: DGEBA); however, the product obtained through Miller-Stephenson had the trade name Shell Epon Resin 828. All products were used as received without further purification.

2.2   Preparation of C$_{12}$-Montmorillonite.

Sodium montmorillonite was treated with 12-aminolauric-acid using the procedure outlined by Usuki *et al*. [9] where a Solution A and B are mixed to effect the exchange reaction. Solution A was prepared by placing 24 mmol of the ω-amino-acid into a 1000 ml beaker containing 200 ml of water that had been preheated to 80 ^{o}C. To this mixture 2.4 ml of concentrated hydrochloric acid (HCl) was added. Solution B was prepared by adding 10 g of montmorillonite to a 1000 ml of 80 ^{o}C water contained in a 1500 ml beaker and stirring. Solution A was then added to Solution B and stirred vigorously for 10 minutes.

The preparation was then filtered and washed 4 times with 1000 ml aliquots of 80 ^{o}C water. The filtrate was then freeze-dried over-night with a Virtis Automatic Freeze Dryer (Model No. 10-010) using a dry ice/ethanol bath for freezing the filtrate. The freeze-dried material was then vacuum dried at 100 ^{o}C over-night in a Fisher Scientific IsoTemp Vacuum Oven (Model 281A) using a dry ice/ethanol bath to trap the volatiles. The treated clay material was then cooled down under vacuum to room temperature and slowly vented to the air. The product was then crushed with a mortar and pestle and

stored in a plastic bottle until use. This material will be known in the remainder of this paper as C_{12}-montmorillonite.

2.3 Preparation of Dog Bone Tensile Test (DBTT) Specimen

The molds for preparing the dog bone tensile test (DBTT) specimens were made with silicon rubber (General Electric) following the procedure described by Drzal and Herrera-Franco [10]. All molds were post cured at 150 °C and rinsed with acetone prior to use. Using Cloisite® 10A and C_{12}-montmorillonite, DBTT specimens containing approximately 2.5 % mass fraction of treated clay were prepared by adding approximately 0.154 grams of clay to 6 g of epoxy mixture. The epoxy mixture consisted of 80 % mass fraction of DGEBA and 20 % mass fraction of DGEBD. The 10 ml beakers containing the clay/epoxy mixtures and a non-clay/epoxy mixture (blank) were then covered with Dura Seal® stretch film and then heated to 50 °C, overnight, on a Corning Stirrer Hot Plate (Model PC-620) while stirring the mixture with small magnetic stirrers.

The beakers containing each epoxy/clay mixture were then placed in a vacuum oven (Fisher Scientific Isotemp Vacuum Oven, model 281 A) set at 50 °C. Stoichiometric amounts of m-PDA crystals (approximately 0.8 g) were placed into another vacuum oven set at 65 °C. After the m-PDA crystals were completely melted, the silicone rubber molds were put into a third vacuum oven that was preheated to 75 °C at -20 kPa, for 20 min. This last procedure dries the mold and minimizes the formation of air bubbles during the curing process.

Approximately 9 min before the preheated molds were removed from the oven, the m-PDA is poured into each clay/epoxy mixture or blank and mixed thoroughly. The mixture was then placed into the vacuum oven and degassed for approximately 7 min. After 20 min, the preheated molds were removed from the oven and filled with the resin mixture using 10 ml disposable syringes. The filled molds were then placed into a programmable oven (Blue M, General Signal, model MP-256-1, GOP). A cure cycle of 3 h at 60 °C followed by 2 h of post curing at 121 °C was used.

2.4 Automatic Tensile Testing Apparatus

Tests were carried out on the automated tensile testing machine shown in Figure 2. The instrument is equipped with a Fostec (150 W) illumination system and a digital camera that scans the gauge length of the dog bone specimen after each strain increment. This machine was built to NIST specifications by Sheldon Wesson, formerly at Textile Research Institute, to monitor the evolution of fiber breaks in single fiber composite specimens composed of glass fibers embedded in an a transparent matrix. A detailed description of this machine is in preparation.

Before testing, samples were polished with emery paper of # 800 and # 2400 to remove stress concentration sites at the edges of the sample. To facilitate strain measurements, transverse fiducial marks (approximately 10 mm apart) were applied to each end of the specimen gage length by a blue color permanent pen. Strains at each step were calculated using the scanned images of each step. In the absence of premature specimen failure, the total strain in the sample at the end of the test was programmed to be about 8.0 %.

Specimen slippage during testing was minimized by placing the specimen in the grips with moderate tightness. The specimen was then loaded in tension by the sequential application of step-strains. During the test, thirty-five step-strains were applied and total deformation was approximately 2.4 mm. Each step-strain was applied at a rate of 85 µm/s and the average deformation in the specimen during each step-strain was 85.7 µm. The delay time between the applications of successive step-strains was 10 min. The image was scanned after every step-strain using a movable camera. The digital image was saved automatically on the computer. The length of gauge length scanned was 23 mm. In the absence of premature failure of the test specimens, the sample was unstressed and removed after the 35 strain-steps.
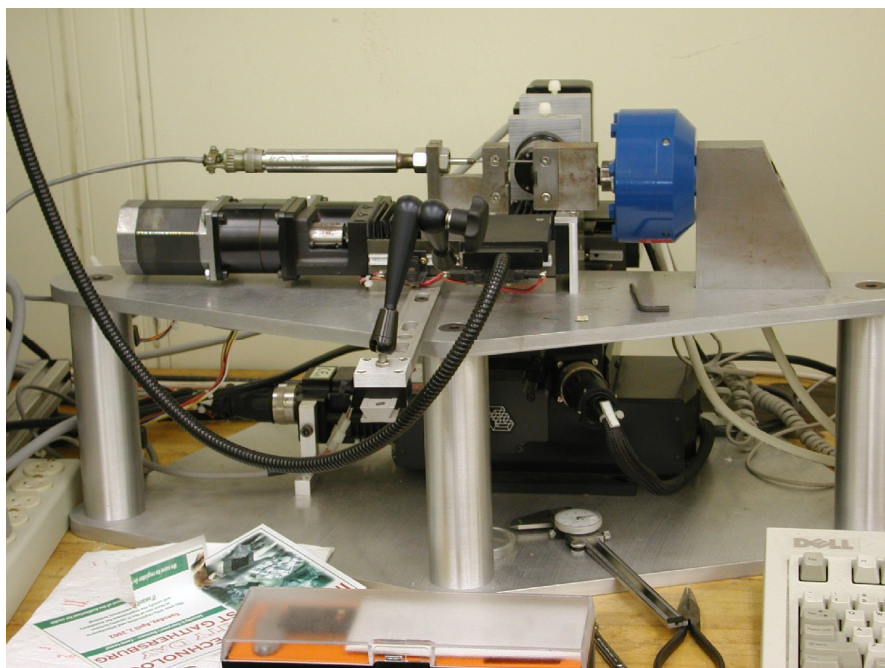
Figure 2.   Automated tensile testing machine.

3   Results and Discussion

3.1   Disposition of Clay Mixtures

The epoxy clay mixtures of Cloisite$^{®}$ 10A and C_{12}-montmorillonite, were transparent and cloudy, respectively, prior to the addition of the *m*-PDA curing agent. Immediate addition of the *m*-PDA curing agent did not cause the Cloisite$^{®}$ 10A epoxy mixture to turn cloudy or the C_{12}-montmorillonite epoxy mixture to turn clear. However, at the end of the curing cycle, both nanocomposites were somewhat cloudy. However, with the 2.5 % mass fraction clay loading, the 2 mm thick dog bone specimens were transparent enough

to clearly read the test on a printed-paper placed beneath each specimen. Although transmission electron microscopic analyis awaits to be done, the cloudiness of the nanocomposite specimens suggests incomplete exfoliation of the clay platelets.

3.2 Stress-Strain Response

The small-strain moduli of the DGEBA/DGEBD/m-PDA epoxy and the nanocomposites prepared from this resin with Cloisite® 10A and C_{12}-montmorillonite were found to be similar, with values of 2.83 ± 19 GPa, 3.08 ± 15 GPa, and 2.55 ± 4 GPa, respectively (see Figure 3), where the $\pm$ values represent one standard deviation about the average value. This is not surprising since the dramatic increase in modulus usually observed with nanoclay inclusion typically occurs at much higher clay loadings (approximately 15 %).
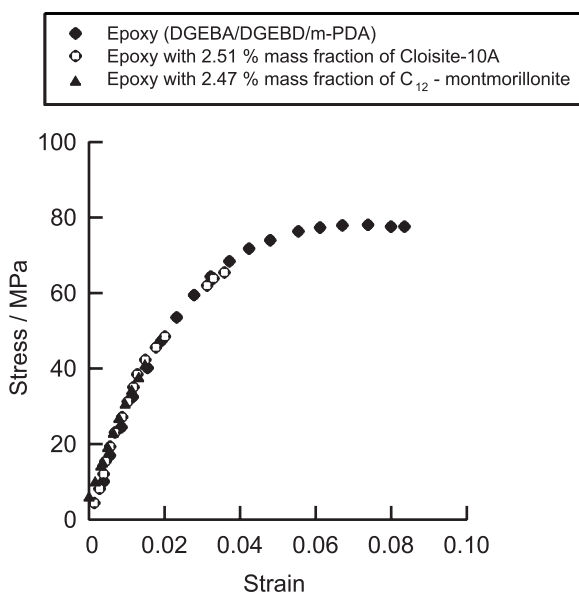
Figure 3. Stress-Strain curves of DGEBA/DGEBD/m-PDA epoxy resin and this resin loaded with approximately 2.5 % mass fraction of Cloisite® 10A and C_{12}-montmorillonite.

The strain-to-failure of the Cloisite® 10A and C_{12}-montmorillonite nanocomposites were found to be 3.6 % and 1.5 %, respectively. The DGEBA/DGEBD/m-PDA epoxy strain-to-failure without clay has been shown in previous experiments to be approximately (10 to 11) %. In Figure 3, the DGEBA/DGEBD/m-PDA epoxy was taken to 8.4 % strain without specimen failure. The reduction in the strain-to-failure with nanoclay inclusion is consistent with previous research results involving glassy epoxy resins.

3.3   Nanoclay Epoxy Failure Behavior

Under constant illumination the images of the Cloisite® 10A nanocomposite taken during the tensile test were found to darken with increasing strain (see Figure 4) above 1 %. In this figure, the darkening of the specimens is evident at (1.3 to 1.5) % strain (strain-steps 10 and 11) and the fiducial marks used to calculate the strain in the specimen are barely visible at the strain increment after 2.00 % strain (strain-step 14). On strain-step 18 the illumination from the light source was increased making the fiducial marks visible again.
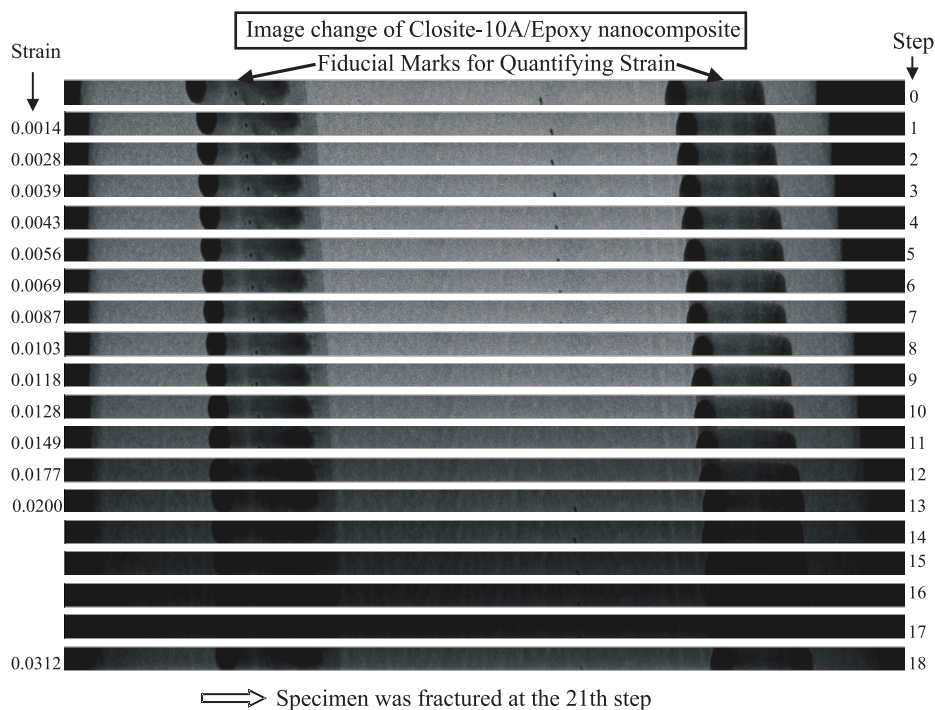
Figure 4. Change in image of Cloisite® 10A nanocomposite with increasing strain.

In Figure 5, the absence of a similar change in the images taken from the tensile test of the DGEBA/DGEBD/m-PDA epoxy resin indicate that the darkening of the images observed in the Cloisite® 10A nanocomposite are not associated with the epoxy resin.
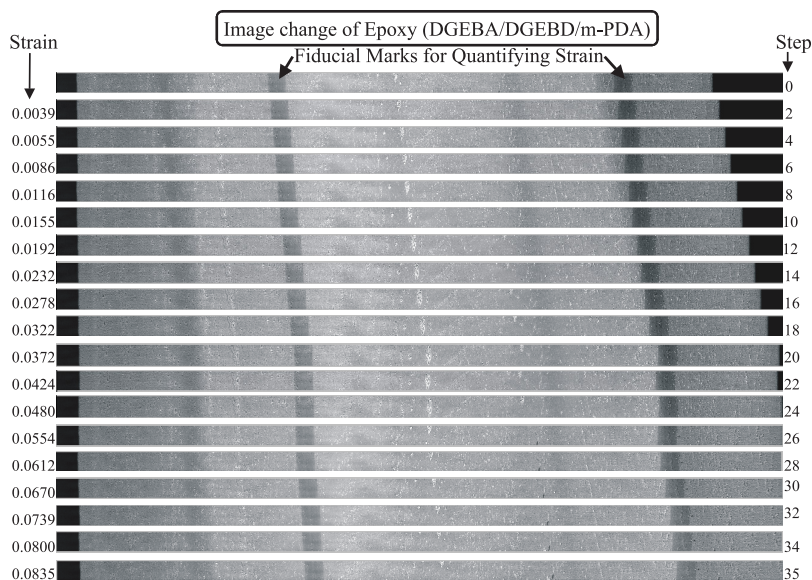
Figure 5. Change in image of DGEBA/DGEBD/*m*-PDA with increasing strain.

The relative reduction in the transmitted light through the Cloisite® 10A nanocomposite with increasing strain was quantified using the NIH image analysis program. The results of this process, shown in Figure 6, indicate an abrupt change in the transmitted light after strain-step 8 (approximately 1.0 % strain).
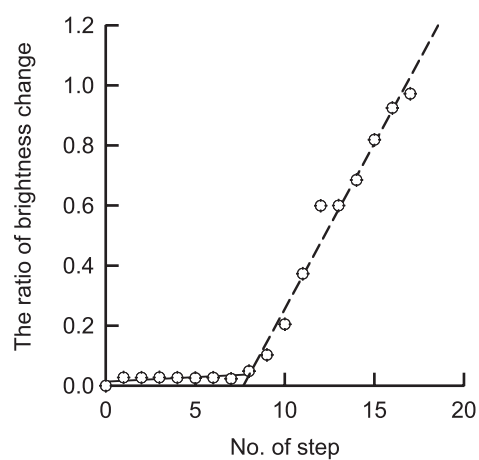
Figure 6. The ratio of brightness change in Cloisite® 10A nanocomposite. All calculations compared to 1st step.

Based on the reduction of transmitted light that occurs in the debonded region surrounding a fiber break in conventional glass fiber composites (see reference 11 and references therein), the image change with increasing strain has been interpreted in terms of clay-matrix interface debonding. Since Cloisite$^{®}$ 10A, like most of the current clay surface treatment technology, contains a hydrophobic alkyl ammonium salt, covalent bonding between the treated clay and the host matrix is formally precluded. Therefore, the interface between the clay and matrix is weak and prone to debonding under tensile loads.

Further support for this line of reasoning was obtained by promoting clay-matrix adhesion. This was accomplished by treating Na^+ montmorillonite with readily available 12-aminolauric-acid to prepare the C_{12}-montmorillonite clay initially used by Usuki *et al.* in the preparation of nylon-clay nanocomposites. Although the carboxylic acid functional group is not the ideal functional group for competing with the amine-epoxy curing reaction, research results from the toughening of epoxy resin with carboxyl-terminated polybutadiene acrylonitrile (CTBN) rubber indicate that covalent bonding between the host matrix and the clay is facilitated by first putting the C_{12}-montmorillonite clay into the epoxy resin for a time to promote reaction between the epoxide and the carboxylic acid group. After this procedure the amine-curing agent is then added to complete the cure of the epoxy resin.

The stress-strain response of the nanocomposite made from this treated clay is shown in Figure 7. In this specimen, no change in image intensity occurred prior to specimen failure, approximately 1.6 % strain. As previously discussed, a reduction in the transmitted light in the Cloisite$^{®}$ 10A nanocomposite was visually observable at (1.3 to 1.5) % strain.
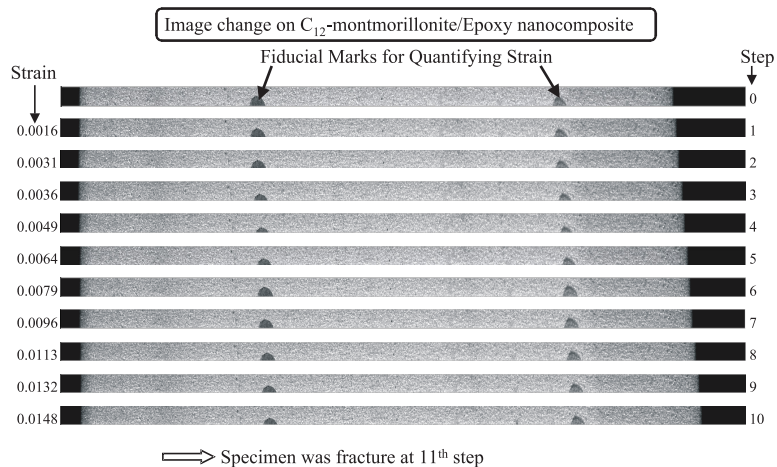
Figure 7. Change in image of C_{12}-montmorillonite nanocomposite with increasing strain.

4   Conclusions

The results indicate that clay-matrix debonding occurs in nanocomposite specimens containing weak interfaces and that the onset of this process can be monitored by a simple test methodology. In the Cloisite[®] 10A nanocomposite, the debonding process begins at approximately 1 % strain and continues until the specimen fails at 3.6 % strain. The process that nucleates the critical flaw (i.e., growing interface crack, nucleation of sub-critical cracks, or other mechanism) will be the subject of future research.

Although the addition of covalent bonds at the clay-matrix interface was achieved by the treatment of Na+ montmorillonite with 12-aminolauric-acid, the strain-to-failure of the resulting nanocomposite was less than the nanocomposite with the weak interface, and the strain-to-failures of both nanocomposites were less than the base epoxy resin. Because of the less than ideal exfoliation of the nanocomposite, these results should not be considered as a definitive indictment against nanoclay inclusion in glass epoxy. The results, however, do suggest the need for continued research. The results presented here do provide a framework for quantifying the failure behavior of nanocomposites.

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AN EXPERIMENT TO DEMONSTRATE THERMAL STRESS INDUCED IN A METAL ROD
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An Experiment to Demonstrate
Thermal Stress Induced in a Metal Rod

National Educators' Workshop
October 19-22, 2003

Michael J. Kozak, School of Technology
Purdue University Programs
Richmond, Indiana

Key Words: Thermal stress

Prerequisite Knowledge: Basic knowledge of how to use a Universal Test Machine and a propane torch (plumber's torch)

Objective: To demonstrate the forces created by thermal stress induced in a metal rod

Equipment and Materials:
1. Universal Test Machine (UTM)
2. Metal rod (1 inch diameter by 12 inch long aluminum rod in this case)
3. Propane torch (plumber's torch)
4. Operator that can safely operate and/or supervise the operation of a UTM and propane torch

Introduction:

Concepts which cannot be visually demonstrated can sometimes be difficult to grasp. Thermally induced stress can be one of these hard to imagine concepts. The author has developed a simple experiment which demonstrates the loads created when a metal rod, which is constrained on both ends, is subjected to a rise in temperature.

Experimental Procedure:

A metal rod with square ends is placed in a Universal Testing Machine (UTM) and the UTM's platens are adjusted such that both platens make contact with the ends of the rod which is at room temperature. The metal rod specimen is then heated with the flame from a plumber's torch. Care must be taken to prevent injury due to contact with the flame or hot objects. Shortly after the flame is applied to the specimen, the force indicator of the UTM will begin to show an increase in load.

Comments:

Since the expansion of the rod is limited by the UTM platens, a force is registered by the UTM which is the force exerted by the rod's constrained contact with the UTM platens as it attempts to expand lengthwise. The load shown on the UTM force indicator divided by the cross sectional area of the rod will indicate the thermal stress in the rod.

The author developed this experiment for a demonstration in a Strength of Materials class. Strength of materials deals with applied loads and their internal effects on bodies [1]. Stress is defined as the internal resistance of a material due to loads [2].

The loads in our experiment are created by the constrained thermal expansion. In this way thermal stress is induced in the metal rod. Away from the ends of the rod, the applied load should be shared uniformly by the entire cross section of the member. In such cases the stress can be computed by simply dividing the total force by the cross sectional area of the member [3].

Stress is an artificial concept [4]. Thermal stress caused by constrained expansion can be difficult for the student to imagine. This experiment demonstrates the forces generated by thermal stress. Witnessing the forces generated may help the student gain an understanding of thermally induced stress.

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Biography:

Since 1999, Professor Kozak has taught applied courses in Mechanical Engineering Technology, Industrial Engineering Technology and Computer Integrated Manufacturing Technology at Purdue University School of Technology in Richmond, Indiana. He has concentrated on courses in strength of materials, dynamics, heat transfer, thermodynamics, fluid power, industrial organization, statistical process control, and automated manufacturing.

He is a registered professional engineer in the state of Ohio, is a professional member of the American Society of Engineering Educators (ASEE) and is chair elect for the Illinois/Indiana section of ASEE. He was awarded a BSME from the University of Akron in 1982 and a MSME from the University of Cincinnati in 1986. From 1982 to 1984 he was a project engineer for B. F. Goodrich. From 1987 to 1999 he was a product development, quality, senior test, reliability, or procurement engineer for General Motors.

SPREADSHEET APPLICATIONS FOR MATERIALS SCIENCE, X-RAY DIFFRACTION AND X-RAY RADIOGRAPHY
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SPREADSHEET APPLICATIONS FOR MATERIALS SCIENCE, X-RAY DIFFRACTION AND X-RAY RADIOGRAPHY

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Abstract

Spreadsheet Applications for Materials Science is and set of modules designed for use in materials science courses. The modules on x-ray diffraction and x-ray radiography described in this paper are tutorial-type modules which introduces these topics and presents the students with a series of spreadsheet-based exercises. The exercises combine lessons in materials science with programming-type skills that require the student to learn systematic approaches to solving problems.

Keywords: x-ray diffraction, Bragg's law, atomic scattering factor, structure factor, Lorentz-polarization factor, 5-fingers of quartz, mass absorption coefficient, Beer's law

Equipment: Microsoft Excel, Corel Quattro Pro or any other modern spreadsheet program.

Prerequisite Knowledge: Basic skills in using spreadsheets, basic knowledge of x-ray diffraction and x-ray radiography.

Introduction:
We know from our laboratory courses that many topics in materials science can be better understood and better appreciated if the students get a chance to work with the material, to solve problems using the tools available in the laboratory. Spreadsheets are a powerful computational tool that is already on practically every instructor's student's computer. Spreadsheet Applications for Materials Science (SAMS) is as set of modules that can be used in much the same way, but this time the tool is the spreadsheet. These modules offer the following:

$ They provide richer, more engaging exercises than traditional homework assignments.
$ They require the use of computers using software that has a very easy learning curve yet teaches skills that can be transferred to formal programming languages such as Pascal, FORTRAN and C and symbolic mathematical programs such as Maple, Mathcad and others.
$ They promote the learning of a systematic approach to exploring scientific issues and solving engineering problems.
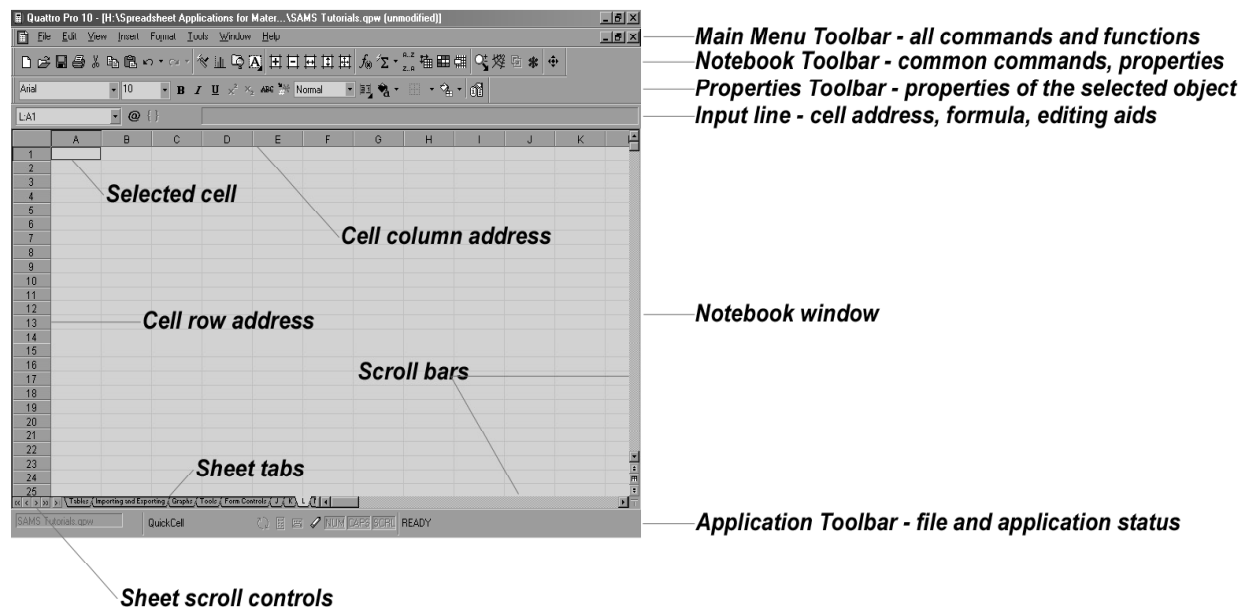
Figure 1 Screen shot of the Quattro Pro desktop. The Quattro Pro and Excel tutorials help students (and instructors) get started using spreadsheets.

The modules that have been developed so far are of two principal types. The first are tutorials that introduce and explore a particular subject. Examples are tutorials on ionic bonding, x-ray diffraction and x-ray radiography. These can be used a supplements to the standard textbook. The other type of module is based on laboratory experiments where the student uses spreadsheets to study a specific phenomena and then to analysis data from an experiment. Examples of this type are diffusion of oxygen in titanium, grain growth kinetic in brass, and the Hall-Petch relationship. In addition, there are tutorials on the use of Microsoft Excel and Corel Quattro Pro, (see figure 1) guidelines for creating a structured, readable spreadsheet, and reference cards that summarize selected features and functions of Excel and Quattro Pro. See table 1 for a summary of the contents of these tutorials.

This paper describes the modules on x-ray diffraction and x-ray radiography. Both are tutorial-type modules that assume they are the student's first exposure to the topic. Each begins with a brief introduction of the topic and then covers the subject in more depth. At the end of each module are a series of spreadsheet exercises. These begin with simple exercises that may involve straightforward visualizations of data, such as creating bar charts showing the mass absorption coefficients of several materials. Subsequent exercises increase in complexity of spreadsheet and general problem-solving skills required and the topic itself. The final exercises are a set of project-scale problems that ask the student integrate the knowledge and skills gained from the previous exercises.

X-ray Diffraction:
The objective of the x-ray diffraction module is teach the basics of x-ray diffraction, focusing on Bragg's law and the intensity of a diffraction peak. (See table 2 for a complete list of topics and their corresponding spreadsheet exercises. Specific applications will be dealt with in future

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modules.)   This module begins with an introduction to the instrument and a description of how an analysis is performed. This is done for the benefit of students who have never seen a diffractometer.   Next, the reflection analogy and Bragg's law are introduced. The spreadsheet exercises associated with this section asks the student to build a spreadsheet that calculates the d-spacing for any plane in any crystal structure. Once the d-spacings are available the student can calculate the Bragg angle for any peak in any structure. The student is now asked to do this for the characteristic copper wavelengths plus the wavelengths of other radiation that may be present in a real diffractometer. See figure 2 for a screen shot of these exercises.

Figure 2 Screen shot (montage) of the first two exercises. By working with simple tables that each perform part of the calculation one can build readable, manageable and extensible spreadsheets.

Figure 3 Calculated 5-fingers section of the diffraction pattern for quartz.

The rest of this module concentrates on the intensity of the diffraction peaks. Each of the terms in the equation 1 is summarized and then the students get to try out each in a series of spreadsheets and to finally put it all together to calculate the actual intensities in the diffraction pattern of selected materials. Comparison to the PDF files should be good. The remaining exercises ask the students to calculate and plot the (101) peak and the 5-fingers peaks for quartz, to import experimental data and compare calculated and measured (figure 3), and to determine the structure and identity of an unknown material from its diffraction pattern. The project-scale exercises ask the student to add instrumental and other artifacts to their calculated diffraction patterns.

$$I = I_0 A \frac{e^4 \lambda^3}{32\pi R m^2 c^4} \frac{1}{v^2} |F|^2 \; p \; \frac{1+\cos^2(2\theta)}{\sin 2(\theta)\cos(\theta)} \frac{e^{-2M}}{2\mu} \tag{1}$$

I	intensity of the diffraction peak
I_0	intensity of the incident radiation
m	mass of an electron
c	speed of light
λ	wavelength of the incident radiation
A	cross-sectional area of the incident beam
R	diffractometer (goniometer) radius
v	volume of the unit cell
$|F_{hkl}|$	structure factor
p	multiplicity factor
2θ	diffraction angle
e^{-2M}	temperature factor (a function of θ)
μ	linear absorption coefficient

The significance of each of the terms in equation 1 is described in the module.

At the conclusion of this exercise the students should have a very good understanding of the basics of x-ray diffraction, the factors that effect intensity and parameters used in a real analysis.
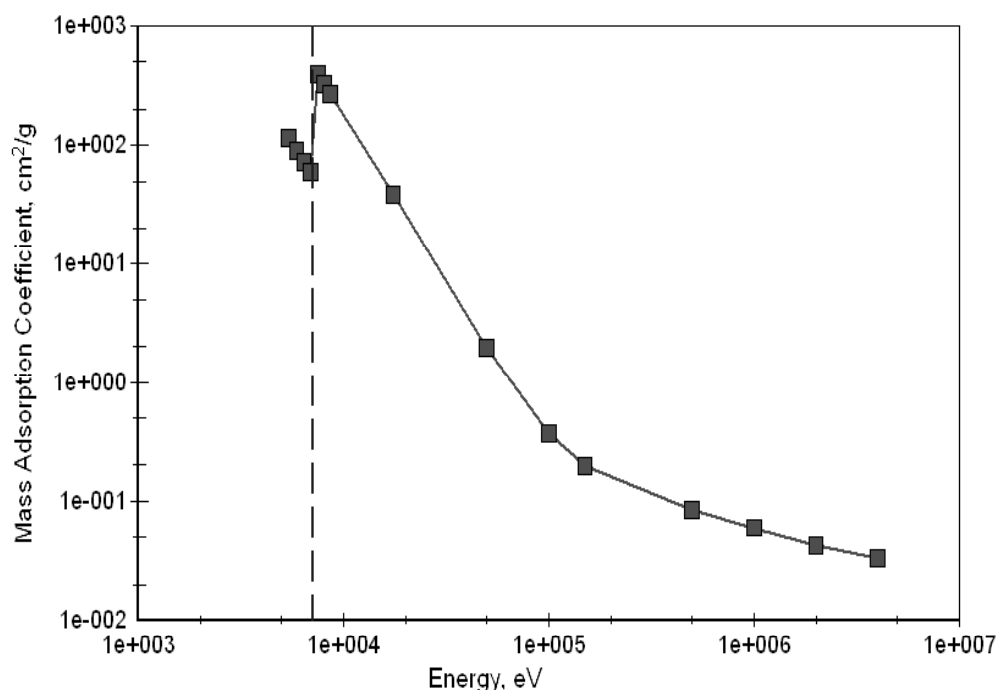
Figure 4 Plot of mass absorption coefficient as a function of energy. This plot is produced in an early spreadsheet exercise in the x-ray radiography module. An exercise in the projects section of this module asks the students to analyze this data in terms of its 8-dependence.

X-ray Radiography:
The x-ray radiography module begins with the absorption of x-rays, continues with the transmission of x-rays and image quality issues and ends with film characteristics and exposing film. The goal is to introduce the student to the principles of x-ray radiography as a materials characterization and inspection technique, but stops short of discussing radiographic practice in detail.

The spreadsheet exercises in this module begin with simple visualization exercises such as creating a bar chart of the mass absorption coefficients of pure elements. The next few exercises expand on this by asking the student to calculate and plot the mass absorption coefficients of alloys and compounds. These spreadsheets are used in many of the remaining exercises, such as calculating the intensity of transmitted x-rays through different thicknesses of material and through a laminated material, estimating the absorption of x-rays in air and the effectiveness of various shielding materials, and plotting the radiographic sensitivity of a particular film and imaging situation. The project-scale exercises at the end of the module begin by asking the student to evaluate the 8-dependence of the mass absorption coefficient. They will see that the well-known 8^3-dependence is only valid of energies less than 150 keV (figure 4). In the other projects the students calculate the transmitted intensity for a sphere, the transmitted intensity and

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exposed film density for a more complex shape, and the final project summarizes the variables in x-ray radiography that the student can use to plan and execute a radiographic exposure.

At the conclusion of this module the student should have a very good understanding of the principles of x-ray radiography as well as a number of very useful spreadsheets that can be used in the laboratory or expanded to include other aspects of x-ray diffraction.

Discussion:
Portions of these modules have been used in courses. In both cases the instructor did not have the completed modules at the start of class and when they did use them they asked the students to try only one or two exercises. This turned out to be more difficult for them than it should have been. The exercises in each module build upon each other, both in terms of the spreadsheet skills required and also the materials science. While some exercises can be skipped, they work best when students start with the easiest ones and make their way through the module to where the instructor thinks is a good place to stop. The primary reason is that few students have ever used spreadsheets for more than making simple plots. The exercises in these modules start at this point and ask for a little more in each succeeding exercise.

Three student reviewers are also reading through each module and working the exercises so that they can provide a student's perspective. Among the feedback provided so far they say that the modules indeed work much better if one does not skip exercises. They also find that the spreadsheets are useful and will keep them. Finally, while they find some of the exercises difficult at first they learn that once they find organize their approach everything gets a lot easier.

The comparison to laboratory experiments made in the introduction also extends to what the work the students submits looks like. If they had difficulty organizing their thoughts before they started working on the spreadsheet, it will usually show in the printout, as it does in laboratory reports. For laboratory reports the students are usually given guidelines, a format, and other advice meant to help them get their ideas straight and to make their work presentable. Many of the spreadsheets students submitted were nearly unreadable. When asked they could explain how they did the calculations, but they also admitted that it would be difficult for anyone else to figure it out on their own. Therefore, guidelines must be given to the students. A handout titled "Suggestions and Hints for Building Your Spreadsheets" was developed. It deals with issues of organization and readability, gives practical advice on analysis tools such as optimizer and solver, creating graphs and printing their spreadsheets. This handout also includes a screen shot, shown in figure 5, of a model spreadsheet. Each module also includes screen shots of the first spreadsheet exercise. Students start each module with a good concrete picture of what their spreadsheets might look like.

These and other modules will be available for downloading at

www.matsci.ucdavis.edu/meier/sams

Other books on the subject of using spreadsheets in chemistry and engineering are listed in the bibliography. Many of the experiment modules in [1] are also good subjects for developing spreadsheet-based exercises.

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Conclusions:

The *SAMS* modules on x-ray diffraction and x-ray radiography provide students and instructors with computer-oriented teaching resources that can be used as supplements to the course's normal text book. These modules ask the students to work exercises using spreadsheets that they will find interesting, challenging and useful. These exercises are designed to provide a fuller understanding of the subjects through modeling of materials phenomena as well as a systematic approach to solving engineering problems.

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Biography:

Michael L. Meier received his B.S. in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph.D. (1991) in Materials Science and Engineering from the University of California, Davis. After a two-year post-doctorate position at the Universität Erlangen-Nürnberg in Erlangen, Germany he returned to UC Davis where he is now the director of Materials Science Central Facilities and is also developing the laboratory teaching program.

Quattro Pro 10 - [C:\Documents and Settings\Adminis...\Sample Spreadsheet.qpw [unmodified]]

File Edit View Insert Format Tools Window Help

Arial   10   B I U   ABC   Normal

Practice:A41   @ { }   Reference Lattice Energy:

	A	B	C	D	E
1	File:	Preparation for the Ionic Bonding Experiment.qpw			
2	Owner:	Mike Meier			
3	Created:	January 4, 2003			
4	Revised:	March 21, 2003			
5	Description:	Practice calculations of ionic bonding energies, equilibrium spacing and density of NaCl-type compounds.			
6					
7	Conversion Factors				
8	To convert from	To	Multiply by		
9	Joules	eV	6.242E+18		
10					
11	Physical Constants				
12	Avogadro's Number:	6.022E+23	per mole		
13	Proton Charge:	1.602E-19	C		
14	Permittivity:	8.854E-12	C^2/Nm^2		
15					
16	Material Parameters				
17	Substance:	KCl	RbF	LiI	
18	Mineral Name:	Sylvite	-	-	
19	Lattice Parameter:	0.629170	0.565160	0.600000	nm
20	Coordination Number:	6	6	6	
21	Number of Cations:	4	4	4	per unit cell
22	Number of Anions:	4	4	4	per unit cell
23	Valence of Cation:	1	1	1	
24	Valence of Anion:	-1	-1	-1	
25	Atomic Weight of Cation:	39.0983	85.4678	6.941	g/mole
26	Atomic Weight of Anion:	35.453	18.9984032	126.90447	g/mole
27	Madelung Constant:	1.747565	1.747565	1.747565	
28	Repulsive Energy Parameter:	2132.5	1851.6	623.1	eV
29	Repulsive Range Parameter:	0.0326	0.0301	0.0366	nm
30	Reference Lattice Energy:	-7.190	-7.866	-7.706	eV
31	Reference Density:	1.988	3.844	4.116	Mg/m^3
32					
33	Calculations				
34	Equilibrium Spacing:	0.3146	0.2826	0.3000	m
35	Equilibrium Lattice Energy:	-1.149E-18	-1.275E-18	-1.180E-18	Joules
36	Mass of Unit Cell:	4.952E-22	6.939E-22	8.890E-22	g/unit cell
37	Volume of Unit Cell:	0.2491	0.1805	0.2160	nm^3
38	Density:	1.988E-21	3.844E-21	4.116E-21	g/nm^3
39					
40	Results				
41	Reference Lattice Energy:	-7.190	-7.866	-7.706	eV
42	Calculated Lattice Energy:	-7.171	-7.957	-7.365	eV
43	Difference:	-0.27%	1.16%	-4.42%	
44					
45	Reference Density:	1.988	3.844	4.116	Mg/m^3
46	Calculated Density:	1.988	3.844	4.116	Mg/m^3
47	Difference:	0.01%	-0.00%	-0.00%	

← Header Section

← Constants

← Variables

← Calculations

← Results

← Graphs and Illustrations

Figure 1. Differences in mearsured and calculated lattice energies.

Figure 2. Differences in mearsured and calculated densities.

Practice / Reference / Madelung Constant / Thermodynamics / E / F / G / H / I / J / K / L / M / N / O / P / Q / R / S /

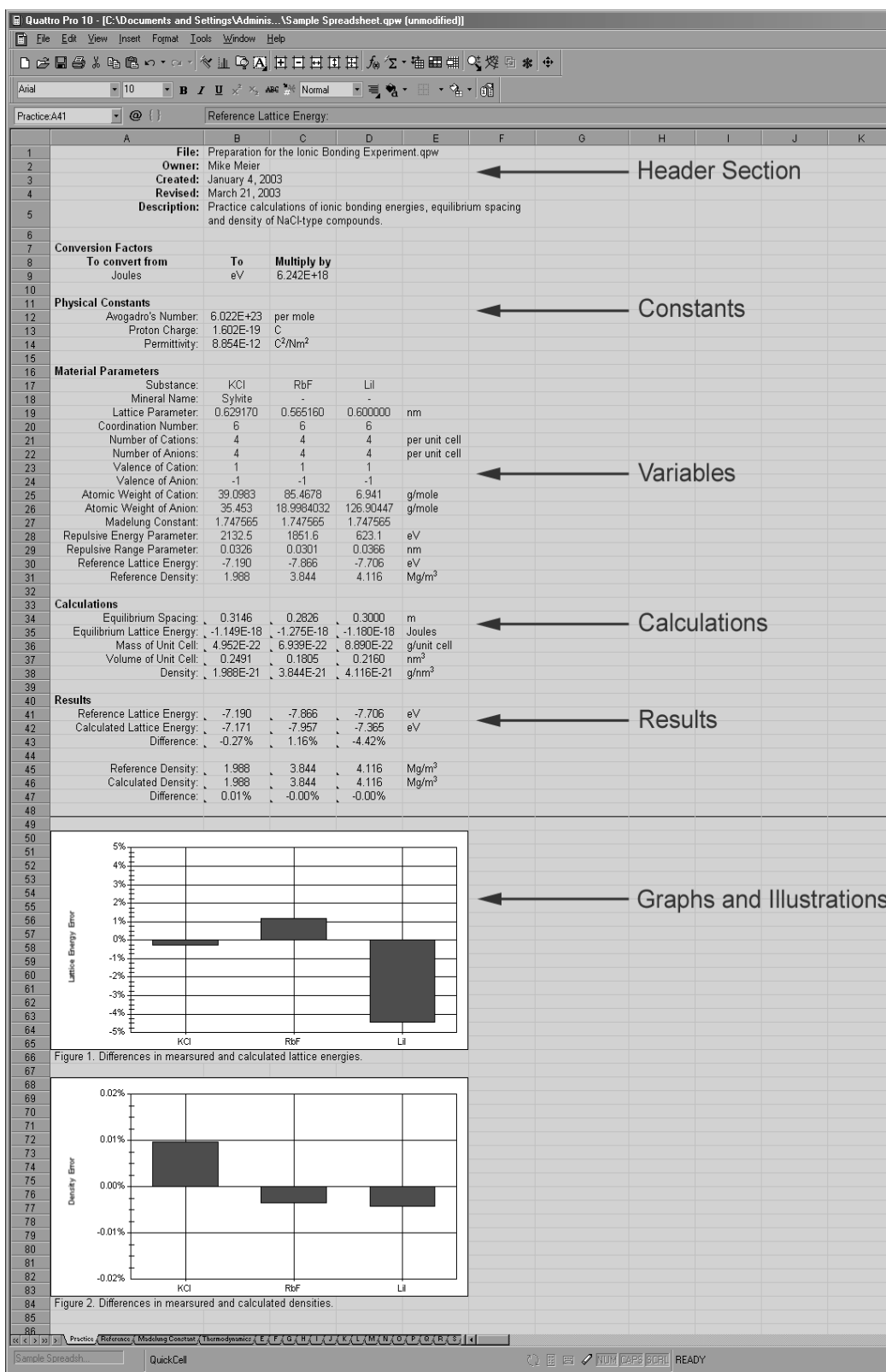Sample Spreadsh...   QuickCell   NUM CAPS SCRL READY

Figure 5 Montage of three screen shots of a single spreadsheet that calculates the lattice energy and density of three ionic compounds. This spreadsheet was built in sections and can easily be modified to perform these calculations for more than three compounds and for other properties.

Table 1. Topics and Exercises included in the Tutorials Module

Section	Content	Exercises
Exploring Microsoft Excel (or Corel Quattro Pro)	Becoming familiar with the features, options and conventions used in spreadsheets	1. Exploring Quattro Pro/Excel
Creating a New Spreadsheet	Opening and initializing a new spreadsheet, emphasizing appearance, organization, annotation and documentation	2. Creating and Initializing a New Notebook
Entering Data	Entering and formatting numeric, text, data, currency and other types of data. Includes custom formatting such as progress bars and text messages such as "Pass/Fail"	3. Entering and formatting numeric data 4. Entering and formatting text 5. Formatting cells
Entering Formulas	mathematical and logical operators, precedence of operations, simple formulas	6. Simple Calculations 7. The cost of cutting class 8. Temperature conversions 9. Currency conversions
Using Functions	Introduction to the 500+ functions available in modern spreadsheets, focusing on mathematical, logical, engineering and statistical functions	10. Common functions 11. Common statistical functions 12. Uncommon functions 13. Engineering functions
Working with Tables and Arrays	How to set up and use the table/array structure to perform calculations	14. Enrollment in engineering majors 15. Gear ratios and speed of a bicycle
Importing and Exporting Data	Importing and parsing data such as ASCII data from data loggers, exporting data and objects	16. Import a comma-separated variable file 17. Import and parse an ASCII text file 18. Export as a comma-separated variable file 19. Export as an ASCII tab-delimited file 20. Export to other spreadsheet formats

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Charts and Graphs	Creating charts and graphs such as bar and pie charts, line and xy graphs	21. Currency rates (bar chart) 22. Enrollment statistics (pie chart) 23. Constructive and destructive interference (xy plot)
Using Advanced Numerical Tools	How to use numerical tools such as sort, solver, optimize, histogram, etc.	TBA
Using Macros	The basics of creating and using macros	TBA
Adding Form Controls to Your Project	Adding Windows-style controls such as buttons, sliders, and combo boxes	24. Adding a Windows-style slider controls
Copying and Pasting to and from other Applications	Copying objects such as graphs, images, drawings and even tables to and from other applications	25. Copying and pasting the contents of a cell to a document 26. Copying and pasting a block of cells to a document 27. Copying and pasting charts 28. Capturing screen shots

Table 2. Topics and Exercises included in the X-ray Diffraction Module

Section	Content	Exercises
A Typical X-ray Diffraction System A Typical X-ray Analysis	Descriptions of x-ray diffraction and analyses, for the benefit of students who have never seen an x-ray diffractometer	None
Geometry of Diffraction	Bragg's law	1. D-spacings for any crystal system 2. Bragg diffraction angles for any source radiation
Intensity of Diffraction	All factors contributing to the intensity of the diffraction peaks	3. Structure factor 4. Lorentz-polarization factor 5. Intensity of diffraction peaks
Practical Aspects of X-ray Diffraction	Unfiltered x-rays, background counts, counting statistics, peak shape	6. Multiple peaks from one reflection 7. $K_{\forall 1}$ - $k_{\forall 2}$ splitting 7. 5-fingers of quartz 8. Comparison of measured and calculated patterns 9. Identifying unknown materials
Projects	Exercises that ask the students to integrate lesson from previous sections to perform calculations that explore this topic further or which reflect real-world situations.	1. Calculated diffraction pattern 2. Calculated diffraction pattern, include artifacts 3. Calculated diffraction pattern, include instrumental parameters

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Table 3. Topics and Exercises included in the X-ray Radiography Module

Section	Content	Exercises
Absorption of X-rays	Mechanisms of absorption, linear and mass absorption coefficients, Z^3 and 8^3 dependence	1. Mass absorption coefficient for pure materials 2. Mass absorption coefficient as a function of energy 3. Mass absorption coefficient for alloys and solutions 4. Mass absorption coefficient for compounds
Intensity of Transmitted X-rays	Beer's law	5. I/I0 for elements, alloys and compounds 6. I/I0 for laminated materials 7. Absorption in air
Image Quality Issues	Source-to-film distance, internal scattering and reflection, geometric unsharpness, projection magnification and distortion	8. Image unsharpness and distortion
Exposure Limits (Radiation Damage)	Exposure, exposure limits, radiation units	9. Exposure limits
Recording the Image	Film, real-time imaging systems, digitized images, radiographic sensitivity, recording an image	10. Radiographic sensitivity
X-ray Radiography Spreadsheet Projects	Exercises that ask the students to integrate lesson from previous sections to perform calculations that explore this topic further or which reflect real-world situations.	1. Wavelength dependence of the mass absorption coefficient 2. Estimating mass absorption coefficients from radiographic images 3. I/I0 profile of a sphere 4. Calculate a radiographic image 5. Parameters for radiographic inspection

USING GRAPHICS TO ANIMATE ACTUAL TENSILE TESTS

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Using Graphics to Animate Tensile Tests

National Educators' Workshop
October 19-22, 2003

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Richmond, Indiana

Key Words: Tensile test, Digitizing, 2-D and 3-D modeling, Microscribe, Rhinoceros

Prerequisite Knowledge: Basic knowledge of tensile testing, 2-D and 3-D modeling and animation

Objective: To digitize, model, and animate a tensile test.

Equipment and Materials:
1. Universal Testing Machine (UTM) with pull test jaws
2. Microscribe Model G2, 3-D digitizer
3. Rhinoceros 3.0 software
4. Appropriate computer to operative software (laptop or desktop)
5. Large tripod
6. Tensile test specimens
7. Dial indicator with magnetic stand

Introduction:

Tensile tests are often used to determine the yield strength and ultimate strength of a material [1]. A sample of a tensile test is often used as a demonstration of material property determination in a strength of materials class. Viewing the tensile test from start to finish makes for an interesting demonstration of the tensile fracture and failure of a material specimen. The failure of the specimen can then be extrapolated by use of example to other mechanical members. This can help the student gain a feeling for the mechanism of tensile failure in mechanical components.

Unfortunately the end result of the tensile test usually consists of knowing the initial sample dimensions, the fractured part and pull force versus length information. The authors, wanted to capture the elongation and fracture of the specimen as a dynamic visual image so it might be replayed as an example of how mechanical components react when subjected to an increasing tensile force until fracture occurs. The authors decided to capture 2-D digital information of the specimen in various stages of elongation until fracture and then use the captured electronic data to create a sequence of 2-D images that could then be used to animate the test from start to finish.

Experimental Procedure:

The experimental setup consists of the UTM and specimen, a dial indicator affixed to the lower UTM platen and monitoring the movement of the upper UTM platen, the microscribe digitizer mounted to a large tripod in front of the platens, and an operator. The digitizer is a spherically jointed articulated arm [2] which has a resolver at each joint and software to calculate the location of the arm's tip in space [3]. The digitizer captures digital dimensional data by the operator placing the tip of the stylus at the location of the position desired, and then pressing a foot switch. By holding the foot switch down continuously while moving the stylus, a series of point locations can be captured digitally. The authors used this continuous method of obtaining data and it was captured at 0.040 inch intervals. The interval length is variable in the data capture software.

Two sets of dimensional data were captured at each step of elongation; one down the left, and one down the right side of the specimen, each beginning at the upper corner where the specimen begins to neck down. Initially, the specimen was recorded with the stylus before a tensile load was applied. Then the specimen left and right sides were recorded as a set after approximately every 0.200 inch movement of the upper platen with a respect to the lower platen as shown by the dial indicator gage. This resulted in seven data collections, the last one being the specimen after fracture.

Each of the seven sets of data was then used to make a unique replication of the specimen's geometry in a 2-D image form.

The 2-D images were created in Rhinoceros 3.0 by using the data files created in the microscribe data capture files to serve as point clouds. The data capture software (Microscribe Utility Software, [MUS]) allows one to save the information in an Excel file [4]. This Excel file was then imported to the Rhinoceros software. The file is used to create a point cloud [4].

The corner points of the beginning of the narrowing of the unloaded sample were used as control points for a NURBS (non-rational Bezier spline) curve in the Rhinoceros software package.

Poly lines were added horizontally to join the specimen's left side and right side data runs which were then joined into a closed contour and then extruded into the initial 0.040 inch thickness of the sample.

The seven images could then be shown on the computer screen rapidly to form a dynamic sequence showing the captured states of elongation and rupture. Images could be further animated by the digitally merging of sequential images (morphing) which would represent the intermediate stages of elongation which were not captured.

Comments:

The sequence of images created as previously described can then be shown as an aid to the discussion of how materials fail in the tensile mode. Images can be created for ductile materials and compared to images of brittle materials. Captured images can be replayed and dissected, whereas simply observing a tensile test and trying to commit the sequence of material shape during elongation and fracturing to memory is prone to error and/or memory loss.

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2. James A Reag, *Introduction to Robotics in CIM Systems*, 2nd edition, Prentice Hall, New Jersey, 1992
3. Microscribe G-2 Users Manual, Immersion Corporation
4. Microscribe Utility Software Manual, Immersion Corporation

Biographies:

Since 1999, **Professor Kozak** has taught applied courses in Mechanical Engineering Technology, Industrial Engineering Technology and Computer Integrated Manufacturing Technology at Purdue University School of Technology in Richmond, Indiana. He has concentrated on courses in strength of materials, dynamics, heat transfer, thermodynamics, fluid power, industrial organization, statistical process control, and automated manufacturing.

He is a registered professional engineer in the state of Ohio, is a professional member of the American Society of Engineering Educators (ASEE) and is chair elect for the Illinois/Indiana section of ASEE. He was awarded a BSME from the University of Akron in 1982 and a MSME from the University of Cincinnati in 1986. From 1982 to 1984 he was a project engineer for B. F. Goodrich. From 1987 to 1999 he was a product development, quality, senior test, reliability, or procurement engineer for General Motors.

Professor Brattain is an assistant professor with the Department of Computer Graphics at Purdue University Statewide Technology in Richmond, Indiana. He received his Bachelor's of Science in General Studies with a Math and Science concentration and a Master of Science degree in Adult Education from Indiana University. The focus of his graduate work has been in technology curriculum design.

He is currently a member of The American Society for Engineering Education (ASEE) and the ASEE-Engineering Design Graphics Division (EDGD). He holds a Master's Certification with the Electronics Technician's Association, International serving on committees that develop certification examinations for Certified Electronics Technicians and Certified Network Support Technicians.

THE PHREE-PHALL PHORMULA OF PHYSICS
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THE PHREE-PHALL PHORMULA OF PHYSICS:
Velocity is the Square Root of 2gh

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Key Words: velocity (v); gravity acceleration (g); energy (potential, kinetic, friction); fluid head (h); hardness (elastic, plastic); toughness (tensile, impact); resilience.

Requisite Knowledge: dimensions (length, area, volume, time); units (U.S., S.I.); mechanics (force, mass, pressure, work, power); fluids (liquid, gas, glassy).

Objective: To explore the applications & implications of free-fall physics, in teaching materials science.

BACKGROUND: The classic formula, "Terminal Velocity Squared = Initial Velocity Squared plus 2gh", often appears in Materials and Mechanics coursework. Richard Attenborough, author and TV producer of "Connections", could well explore this topic.

   We see free-fall velocity to be independent of mass, as Galileo drops various masses from the Leaning Tower of Pisa. Likewise, Torricelli's Jet Velocity (squirting from a tank's side-outlet into the atmosphere) is under static-head from the top-surface of an open tank. But his basic empirical formula is directly derived from Bernoulli's Equation: three heads (static, dynamic, and elevation) = hydraulic head, which is constant for pipe-flow, neglecting friction. All heads are "feet (metres) of fluid flowing". Even "head-loss" is f(L/D)(Vsquared/2g).

   Recall the impact velocity of a drop-weight tester for welded plates; the ball-and-tube test of Malay Snails; a swinging pendulum striking a Charpy sample; a drop-forge hammer; a pile-driver tup; a Shore Scleroscope ; a Proceq hardness tester. Similarly, this is sky-diver velocity, jumping from an airplane and falling a known distance. It is the vertical velocity-component of an Izod half-bar, ejected by Tinius-Olsen pendulum per ASTM #E23. We also calibrate flowmeters: orifice, nozzle, venturi, pitot-tube. Such applications may ignore friction, drag, and windage; often they include correction factors. Laboratory experiments with basic equipment are described.

EQUIPMENT: a) Simple Scleroscope (Rebound Hardness Test)
           -Brinell Ball, 10-mm diameter, hard steel
           -Plastic Tubes, 0.5-inch I.D., 18"-36" long (say 45-90 cm)
           -Flat Base (oak desk, or 1" steel plate) to support sample
           -Ring Stand (to support tube) & carpenters level (for vertical tube)
           -Metre Stick (to measure drop-height & rebound of ball)
           -Assorted Metal Samples (Steel, Al, Cu, Brass; 2"square by ½" thick)
        b) Torricelli Tank (with side outlets of varied shape)
           -Milk Bottle (gallon) or Pop Bottle (2 or 3-litre)
           -Sink (to catch jet-spillage)

c) Simple Impact Pendulum (Swinging Weight)
    -Socket Head (for changing spark-plugs; the tup)
    -Nylon Line (from fish-pole or lawn-trimmer; tied to tup)
    -Ring Stand (to support pendulum) with Sample Holder
    -Samples (hard-boiled egg; snail shell).
d) Impact Pendulum (Tinius-Olsen, floor model#84) with 60-lb tup
    and 4.4-ft vertical fall (264 ft-lb capacity). Charpy anvil and
    ASTM#E23 test coupons for metals.
e) Impact Pendulum (Tinius-Olsen, table model#892) with electronic
    display and plastics test bars.
f) Shore Commercial Scleroscope (table model#C-2, scale 0-140) with
    hammer size 0.234".
g) Equo-tip Hardness Tester (Proceq model D) for metal samples.
h) Paro-tester (Proceq model P) for hardness profile of roll products.

COMPARING SCLEROSCOPES:

a) Our Ball-and-Tube experiment involves dropping a steel Brinell ball-
   indenter thru a transparent tube, which rests on a firmly supported
   sample of metal; a ball-bearing, marble, or plastic ball could be used.
   Hardness is measured directly as "% rebound", in elastic collision
   between ball and sample; the harder the metal, the higher the bounce.
   Provide a smooth surface; assume homogeneous structure; take all
   measurements from sample surface to ball bottom. Another approach
   is to compare sounds for various materials (tick-tock, ping-pong);
   paper-makers thump their "jumbo-rolls" of tightly wound product,
   using a billy-club and hearing differences in density or moisture. A
   popular trade-show exhibit involves dropping a series of ball-bearings,
   which bounce uniformly from tilted anvils and then disappear through
   a small hole in the wall; a few non-spherical, off-quality balls litter the
   floor.
b) The commercial Shore Scleroscope shows relative rebound for a
   standard tup and drop height. Strangely, every 10-divisions are about
   16-mm, with no correlation to inches.
c) The commercial Equo-tip tester electronically displays the relative
   rebound velocity of a magnetic tup, which correlates with the square-
   root of our simple "% rebound". Software also gives corresponding
   Brinell, Rockwell, & Knoop hardness numbers for metal samples.
   Unlike a simple free-falling tup, the electronic tup reads upside-down
   or sideward; however, ferro-magnetic samples may interfere with the
   magnetic coil of this tup.
d) The commercial Paro-tester electronically displays relative rebound
   velocity, which correlates with the square-root of simple"% rebound".
   Software gives statistics for multiple readings of hardness profile, for

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rolls of tightly wound paper, foil, or film production. This tup also reads upside-down or sideward.

OBSERVING TORRICELLI JETS: Cut 4-holes (about 1-cm diameter) in the side of a plastic bottle, spaced vertically (say 10-15-20-25 cm) in a 2-litre pop bottle (about 30-cm tall). Fill the bottle to the top & observe how jet-length increases with water-depth. Velocity is the square-root of 2gh, when g is 980.1 cm/s/s (32.174 fps squared); and head (h) is measured to the center of each hole. Notice each jet reaches a minimum diameter (vena contracta) as flowlines become parallel at atmospheric pressure. For uniform flow (1-dimensional) we can equate the 3-Bernoulli heads (elevation, pressure, and velocity at vena-contracta) to the elevation head of the top surface. This assumes zero velocity & atmospheric pressure, at the tank surface, and zero elevation head for the jet.

   Next we cut odd-shaped holes (at the 25-cm depth) and compare the jet shapes. Make a diamond (10-mm by 10-mm) standing on end; then a vertical ellipse (3-mm by 10-mm); and a horizontal ellipse (10-mm by 3-mm). Note the braided effect, as each new jet over-shoots the circle (vena contracta) and makes nodes. We can only assume atmospheric pressure to be uniform throughout a circular cross-section (A), where 1-D jet velocity is again the square-root of 2gh. And continuity prevails for incompressible flow: Q=AV.

CONCLUSION: Get wisdom, get knowledge, get power, get technical, get connections.
                And with all thy getting, get understanding. That's the formula.

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1) Rouse, Hunter, & Ince, Simon, "History of Hydraulics", Iowa Institute of Hydraulic Research, Iowa City, 1957.
2) Widener, E.L., "Brinelling the Malay Snail", NASA Conference Publ.No. 3354, Hampton, VA, July 1997.
3) Vennard, John K., "Elementary Fluid Mechanics", 3rd ed., John Wiley & Sons, New York, NY, 1954.
4) Janna, William S., "Introduction to Fluid Mechanics," PWS Engineering Div. of Wadsworth), Boston, MA, 1983.
5) Parker, Sybil B. (ed.), "Dictionary of Scientific & Technical Terms", 5th ed., McGraw-Hill, New York, NY, 1994.

        Biography: Prof. Widener has taught at Purdue University since 1978, concentrating on mechanics, materials, recycling, & communicating. Ed was in Malaysia from April 1996-June 1996, teaching Metals Labs for new technology teachers. Member of ASEE, ASME, ASM, ISA, & TAPPI. Registered P.E. in NY & IN. ABET-visitor (1983-1990). NSF grants reviewer in 1989 & 1990. Taught night classes (1974-1977) in Indianapolis (IUPUI) & Danville (IL). Degrees from Purdue are BS'49 (physics) & BS '51 (ME). MS '62 (Hydraulics) from Univ. of Kansas. Between 1952-1978, Ed was a process or project engineer for Continental Group, Baker-McHenry-Welch, Kimberly-Clark, E.I.DuPont, Union Carbide, & U.S.Steel. In WWII, he was U.S.Navy S1/c aboard cruisers Vicksburg & Astoria.

MATERIALS ON MISSE
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Materials on MISSE

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Materials

International

Space

Station

Experiment

ISS

- *MISSE 1*
- *MISSE 2*
- *MISSE 3*
- *MISSE 4*
- *MISSE 5*

MISSE (Materials International Space Station Experiment) Specimens

2-K1
Kapton

2-K2
Kapton with 10% by weight
aluminum acetylacetonate (Alacac)

1-year AO plus Solar exposure

1-J11
Kapton

1-J12
Kapton with 10% Alacac
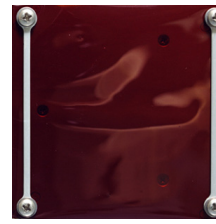
1-J13
Kapton with 15% Alacac

1-year Solar (no AO) exposure

MISSE 1

AO + UV

UV
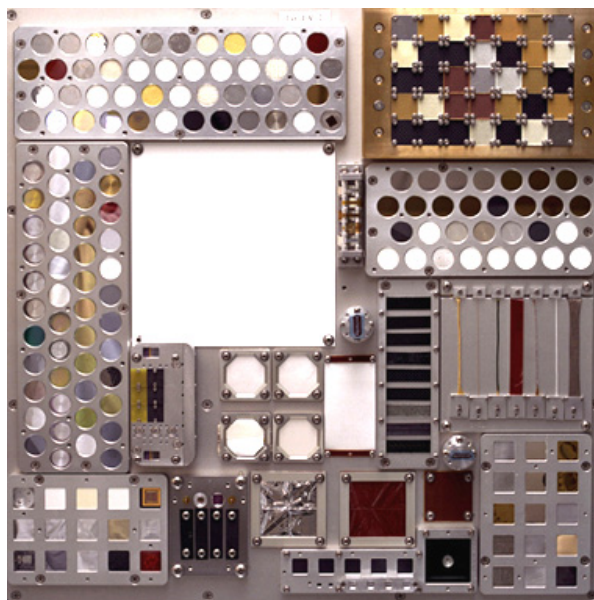
Materials
International
Space
Station
Experiment

MISSE 1 - UV
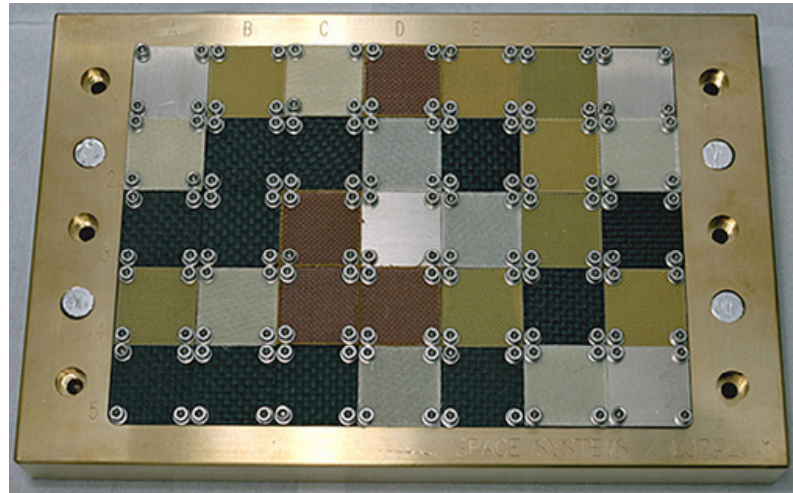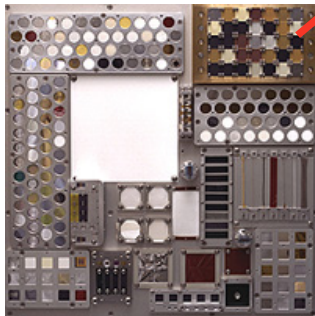
35 Low Z / high Z / low Z layered radiation shielding materials with 4 thermo - luminescence detector (TLD) stacks - - Space Systems Loral and Physical Sciences, Inc.

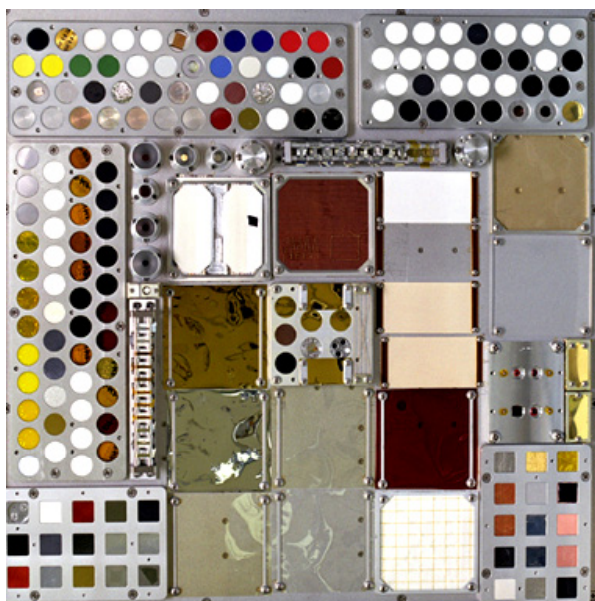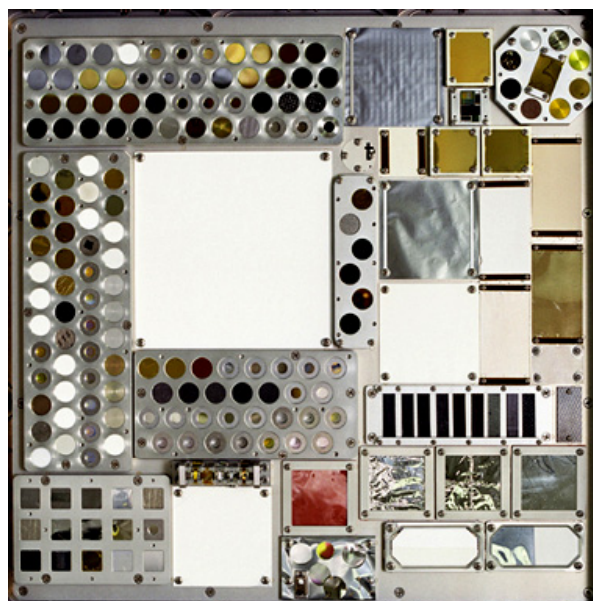- MISSE is managed by NASA Langley

MISSE 2
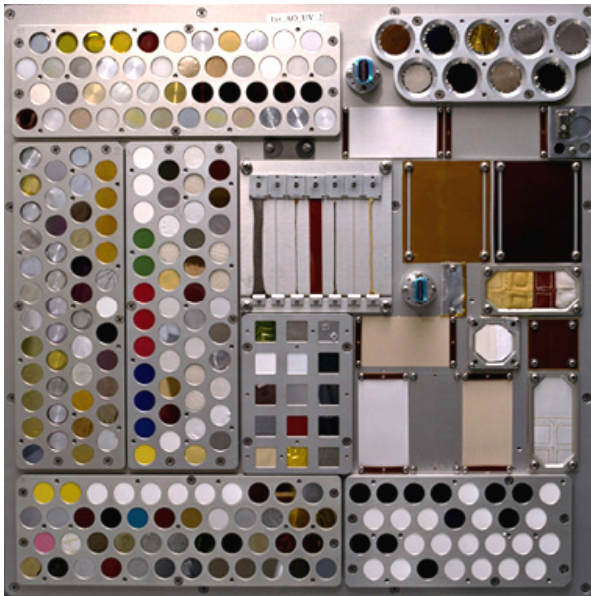
AO + UV   **UV**
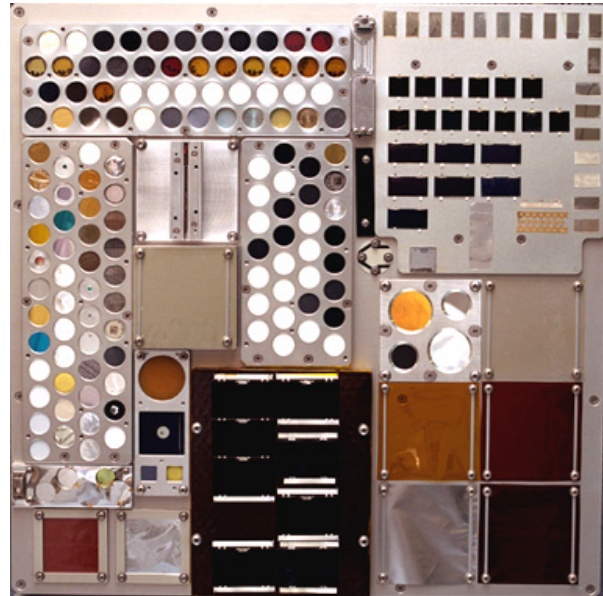
MISSE 3

AO + UV

UV

MISSE 4

AO + UV

UV
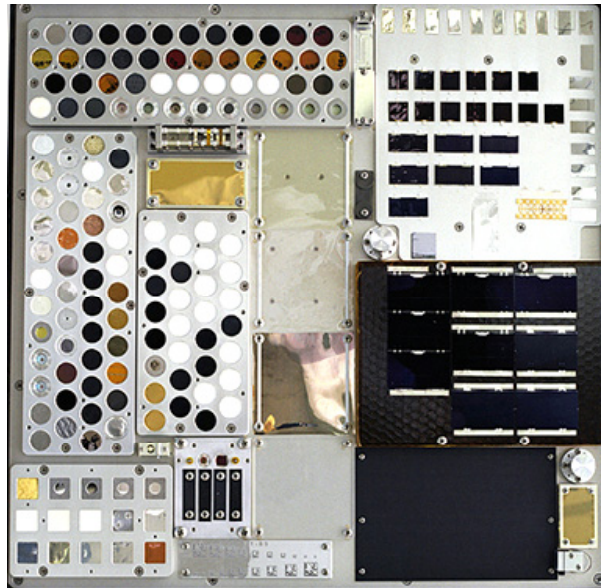
MISSE 5

Boron-Containing Polymers on MISSE 5

Ultem with 20% borane
Ultem with 15% borane
Ultem with 10% borane
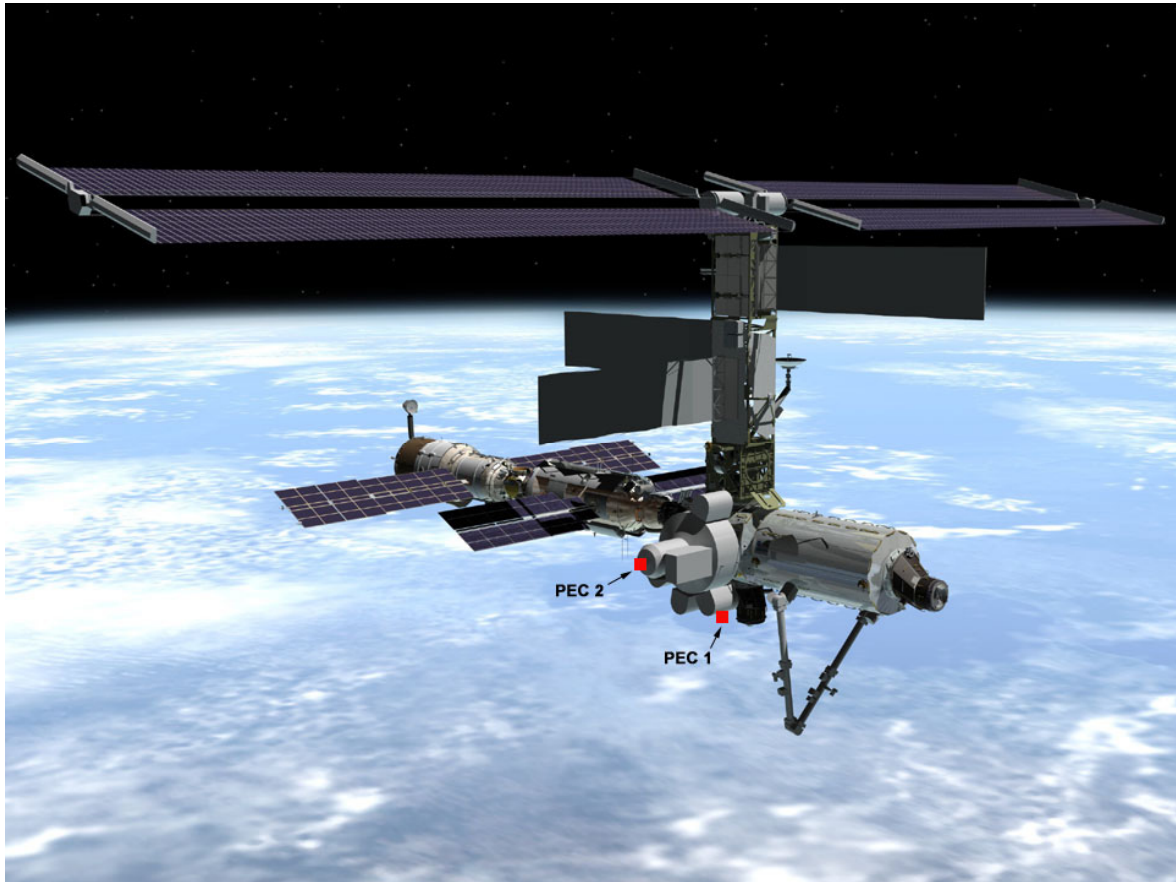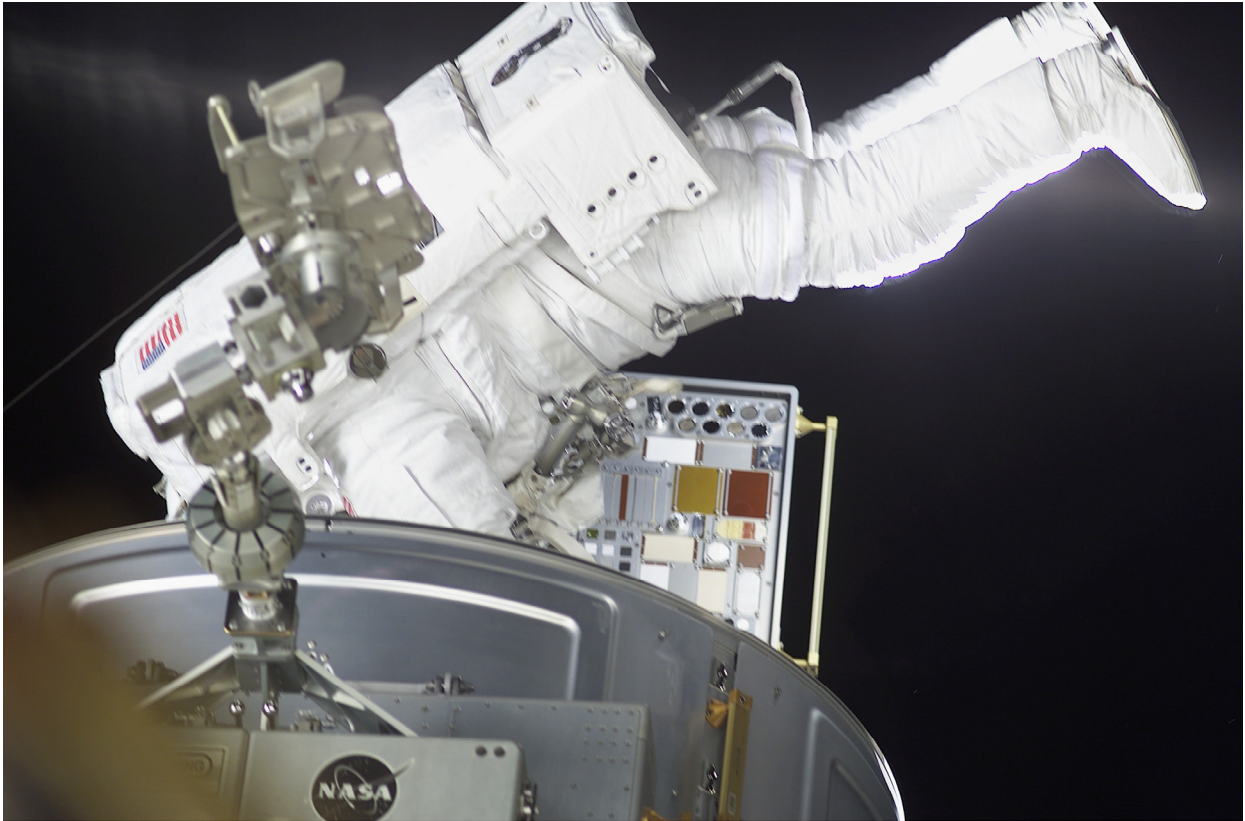
Pure Ultem
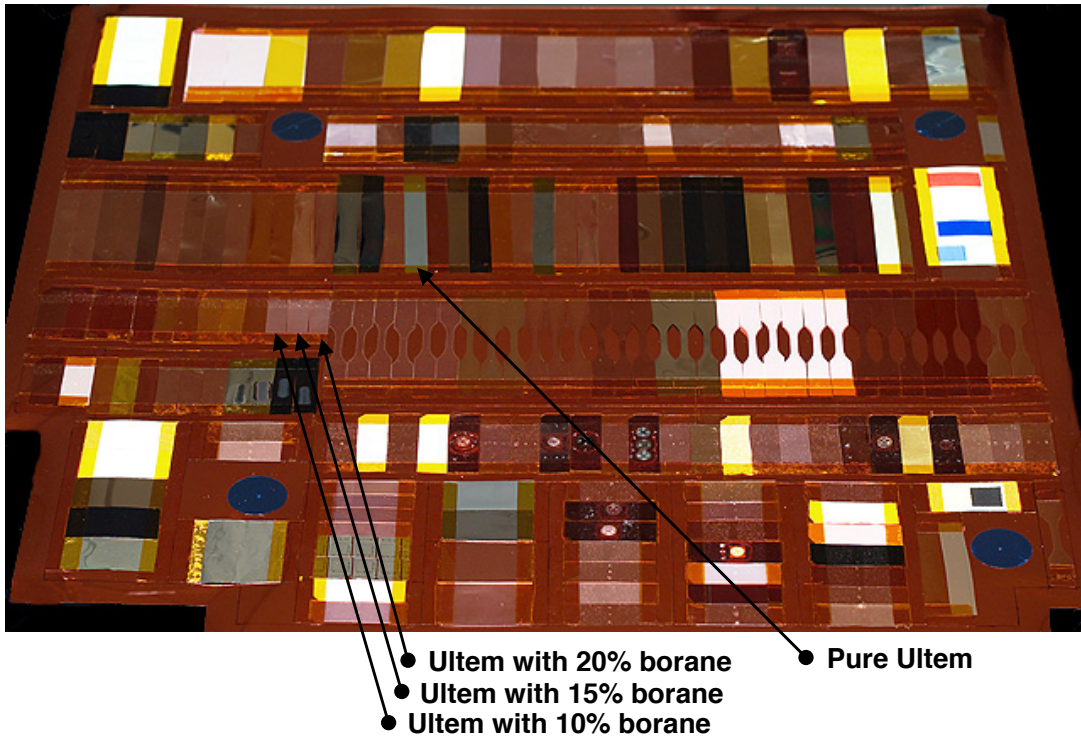
- Films for space-environmental durability testing

Passive Experiment Carriers

MISSE

S105E5306 2001/08/16 19:17:06

MISSE

MISSE
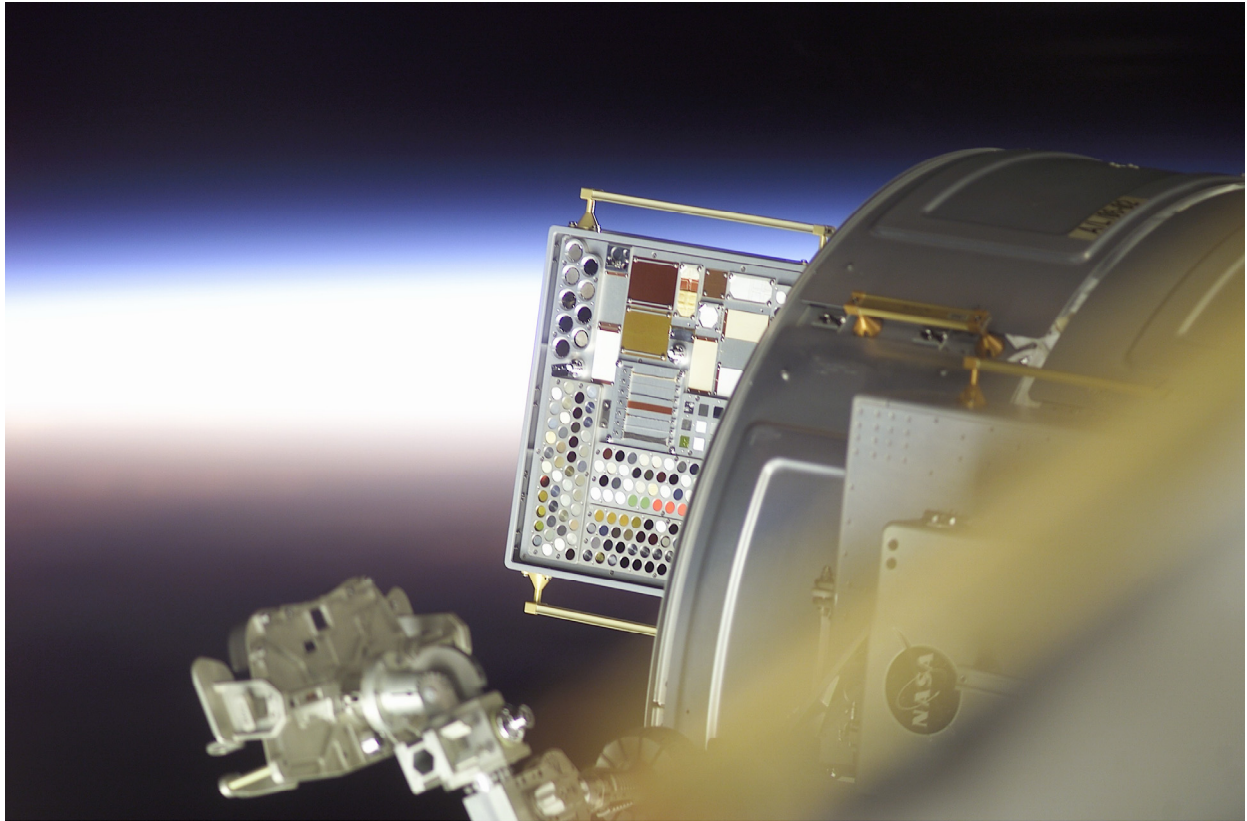
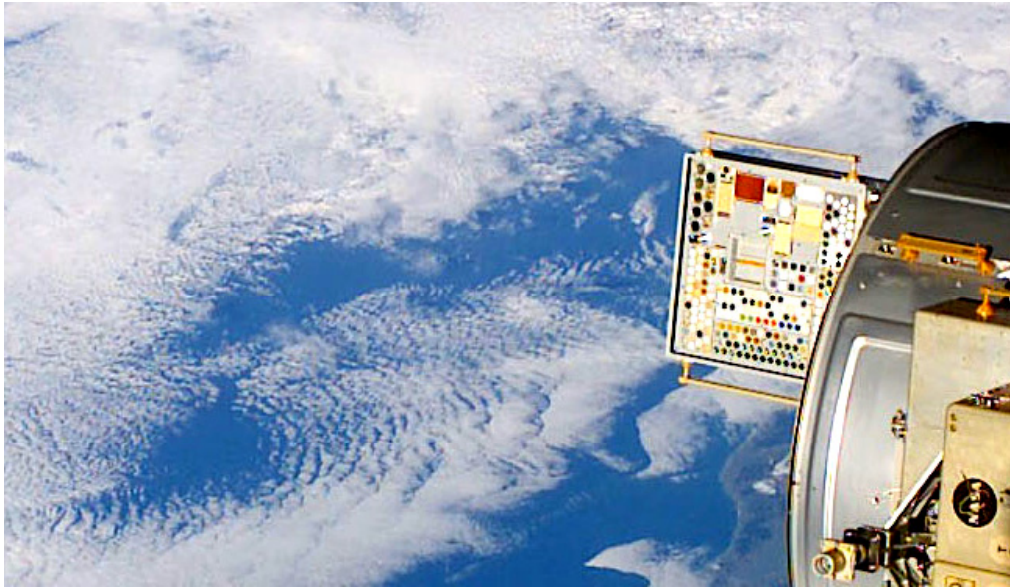S105E5342 2001/08/17 23:00:53

MISSE

MISSE

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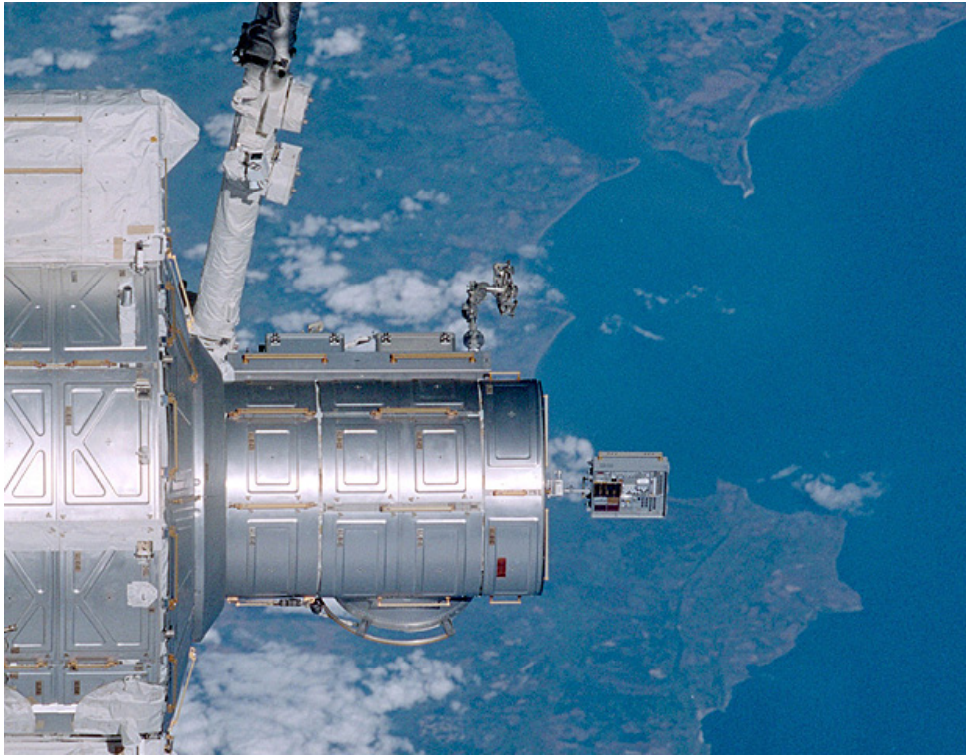
912

Activities for MISSE

- Investigate and develop improved thin films concepts for durability, radiation shielding, and electrostatic control
- Characterize films for mechanical and other materials properties
- Compile and report data after retrieval and analysis
- Ultimate proof of the performance in the space environments

PROGRESS TOWARD DYNAMIC COLOR RESPONSIVE "CHAMELEON" FIBER SYSTEMS
Richard V. Gregory

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Old Dominion University
Norfolk, Virginia 23529

Telephone 757-683-3274
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Richard V. Gregory

Progress Toward Dynamic Color Responsive "Chameleon" Fiber Systems

Richard V. Gregory

Old Dominion University

Dean, College of Sciences

National Science Foundation Center

Advanced Fibers & Films
Clemson University, Clemson, SC

National Educators Workshop
October 22, 2003

C A E F F

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DARPA

C A E F F

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Introduction

- **Early Conducting Polymers**

  – Polyacetylene

  – Polypyrrole

  – Polythiophene

  – Polyaniline

- **Early Problems**

  – Insoluble

  – Not Processable Once Formed
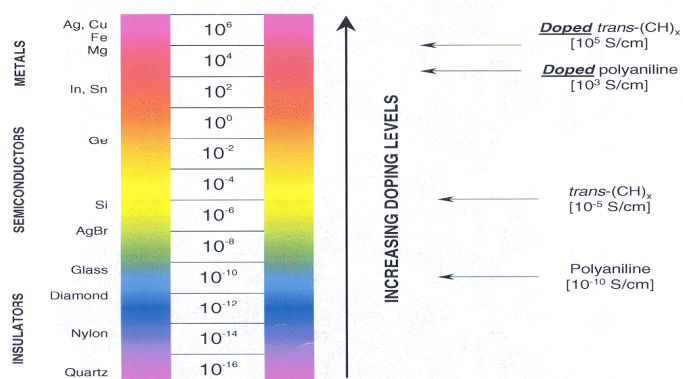
  – Non-melting

  – Characterization

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Insulator to Conductor Transition

Conductivity of Electronic Polymers

Applications

Devices

- Sensors and Biosensors
  - Optical sensing
  - Chemical agent sensing
  - Biological agent sensing
- Electromechanical Actuators
- Organic Electronics
- Electro-optic Devices
  - LEDs, optical switches, etc.
  - Amplification and lasing
- Energy Storage and Conversion
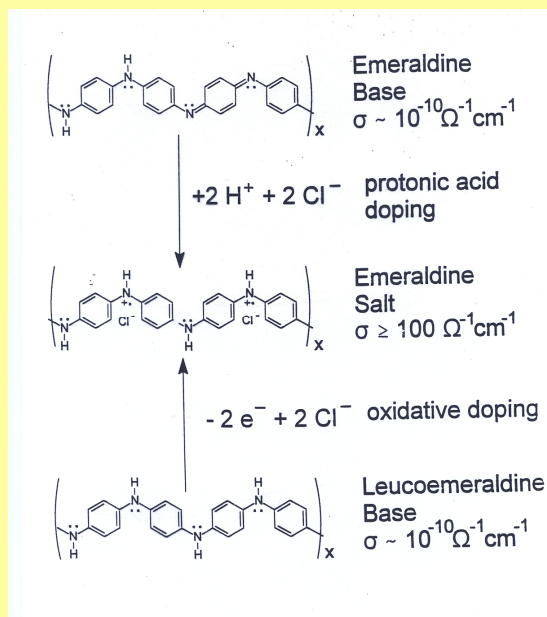 - Batteries
  - Solar cells

Potential Applications

- Mars environment suits
- Extra-vehicular suits
- On-board displays
- On-board sensing
- Bio-Sensors
- Organic Electronics
- Etc.

C A E F F

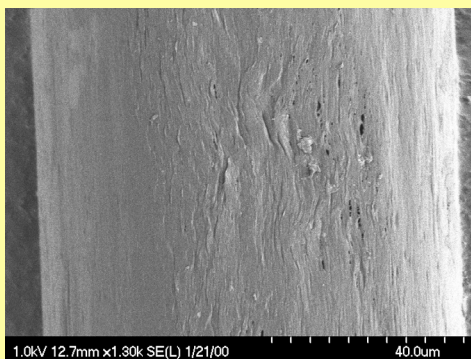# Structure/Property Relationships
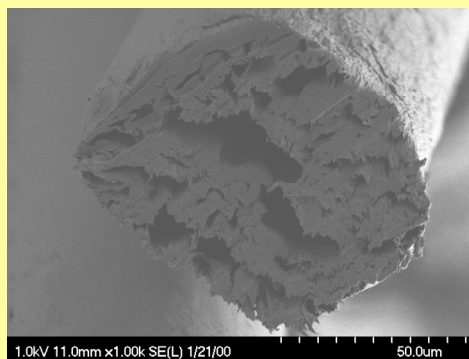

POLYANILINE

Processable

Starting Material
Available in Large Bulk Quantities

Note the oxidation states.

C A E F F

Continuous 80 Filament 12 d/f PANI Yarn Bundle Produced

Filament Surface From 80 Filament Bundle

As Spun LEB/PANI Fiber From 80 Filament Bundle (void spaces reduced upon draw down)

C A E F F

Fiber and Film Processing

Polyaniline monofilament and 80 filament yarn bundles can be spun from leucoemeraldine base or emeraldine base

S. S. Hardaker, B. Huang, A. P. Chacko, and R. V. Gregory, *SPE ANTEC '96*, **42(2)**, 1358 (1996).

A. P. Chacko, S. S. Hardaker, B. Huang, and R. V. Gregory, *Mat. Res. Symp. Proc.*, **413**, 503 (1997).

A. P. Chacko, S. S. Hardaker, R. V. Gregory, and R. J. Samuels, *Synthetic Metals*, **84**, 41 (1997).
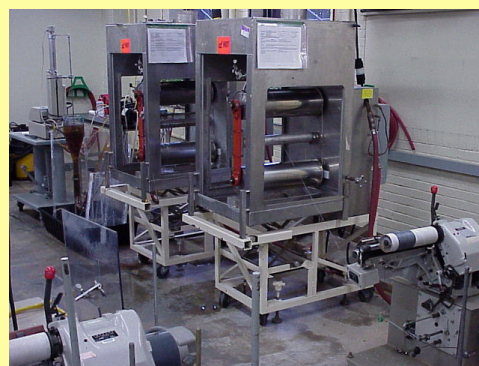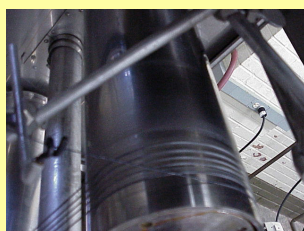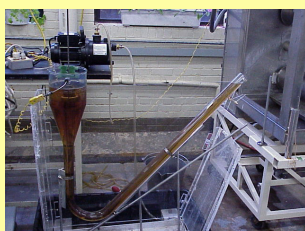
CAEFF wet spin line

C A E F F

ADVANCES MADE

Slide[*] presented by Professor Alan MacDiarmid, 2000 Nobel Chemistry Laureate, during his Nobel address December 6, 2000 in Stockholm Sweden showing Polyaniline fiber spun in CAEFF laboratories.

Nobel Prize Laureate

NP22

Spun Polyaniline Fiber
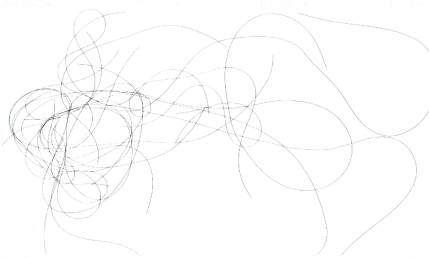
* Fiber slide courtesy of Nobel Laureate Professor A. MacDiarmid

- B.J. Mattes and H-L. Wang, US Patent #6,099,907 (Aug 8 2000), Santa Fe Science & Technology, Inc., Santa Fe, NM.
- R.V. Gregory in *Handbook of Conducting Polymers*, 2nd Ed. Marcel Dekker, T. Skotheim, R. Elesenbaumer, J. Reynolds, Eds., (1998) p437.

C A E F F

Oxidation States In Polyaniline

A.

B.

C.
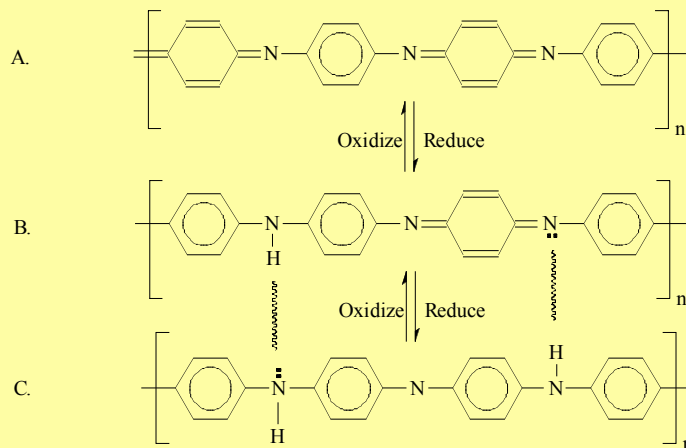
A.   Fully Oxidized

B.   Partially Oxidized

C.   Fully Reduced

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Fiber and Film Processing

Constitutive Equations

-Elastic Dumbbell Mode: For Polymer Solution

$$\text{We}\langle QQ\rangle_{(1)} + \{\langle QQ\rangle - \delta\} + \alpha\{\langle QQ\rangle - \delta\}\cdot\{\langle QQ\rangle - \delta\} = 0$$

$$\tau_p = -\frac{(1-\beta)}{\text{We}}\{\langle QQ\rangle - \delta\}$$

-Rigid Dumbbell mode: For Polymer Gel

$$\langle S\rangle_{(1)} + \frac{1}{\text{We}}\langle S\rangle - \frac{1}{3}\left(\nabla v + \nabla v^T\right) + 2\{\kappa : \langle uuuu\rangle\} = 0$$

$$\tau_p = -3\left(\frac{1-\beta}{\text{We}}\right)\langle S\rangle - 6(1-\beta)\kappa : \langle uuuu\rangle$$

$$\langle S\rangle = \langle uu\rangle - \frac{1}{3}\delta$$

C A E F F

Fiber and Film Processing

Diffusion Equations

$$\rho\left(\frac{\partial C_i}{\partial t} + v \cdot \nabla C_i\right) = \frac{1}{r}\frac{\partial}{\partial r}\left(D_i(T)r\frac{\partial C_i}{\partial r}\right) + \frac{\partial}{\partial r}\left(D_i\left(\frac{\partial C_i}{\partial z}\right)\right)$$

i=0	NS/Polymer Solution
i=1	NS/polymer Gel
i=2	S/Polymer Solution
i=3	S/Polymer Gel

Boundary conditions

Interface: Gel/solution
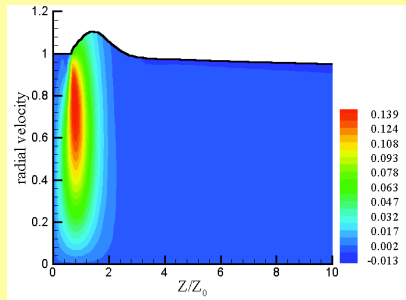
i=0,2

$$D_i\frac{\partial C_i(r,t)}{\partial r} = D_{i+1}\frac{\partial C_{i+1}(r,t)}{\partial t}$$

$$C_i(r,t) = C_{i+1}(r,t)$$

C A E F F

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Fiber and Film Processing

Draw Ratio=5
Re=2.8e-5
We=2
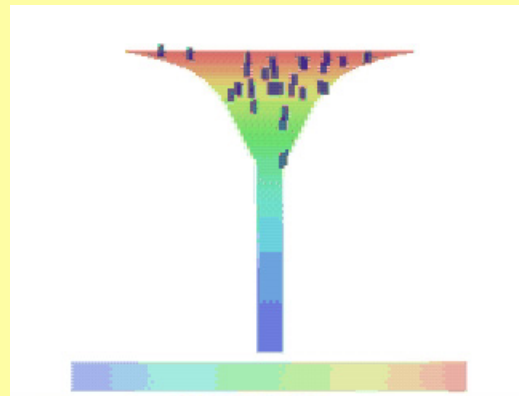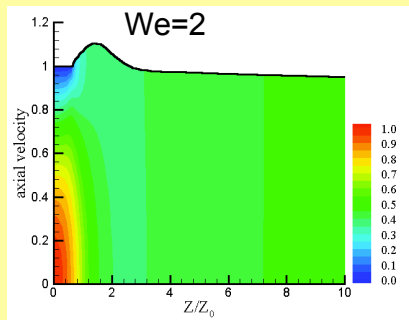
C A E F F

Organic Film Lasers

Film Laser Relies on Internal Reflections from Reflective Surfaces

Wave Guided

Reflective surfaces

Active Polymer
ie: MEH -PPV

C A E F F

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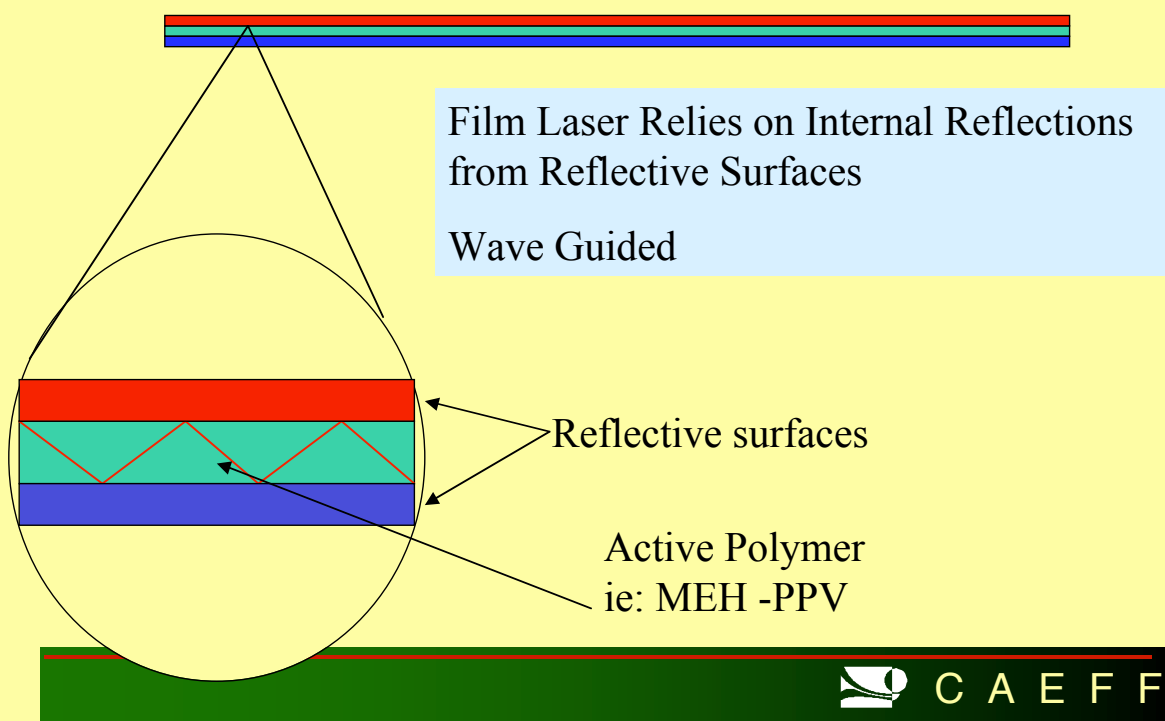
Fiber Based Lasers

All Organic Micro-ring Fiber Laser
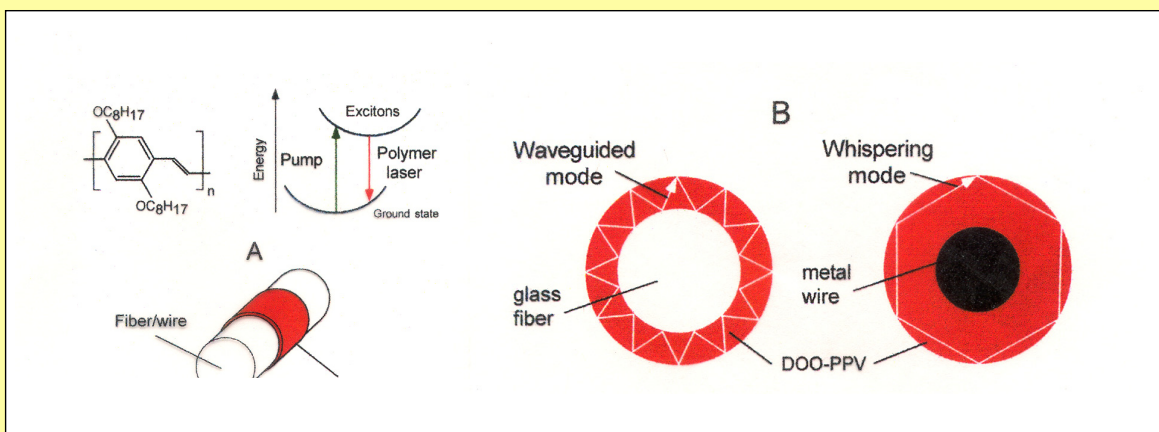
DOO-PPV   dioctyloxy-polyparaphenylene vinylene

C A E F F

Laser Mode Distribution In DOO-PPV Micro-Ring Lasers
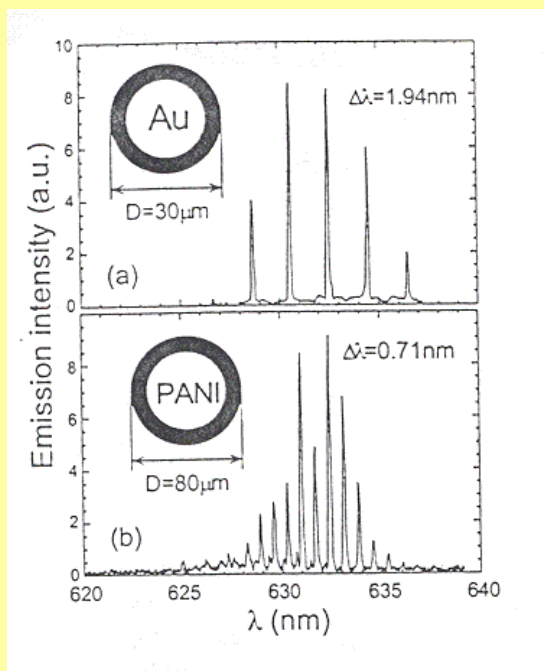
C A E F F

Cylindrical Microrings

Laser "Burst" from an excited DOO-PPV micro-ring on an optical fiber. Fiber is 125 microns and the laser cavity is 15 microns. Emission scatter due to water vapor used to enhance the image

C A E F F

Cylindrical Microrings
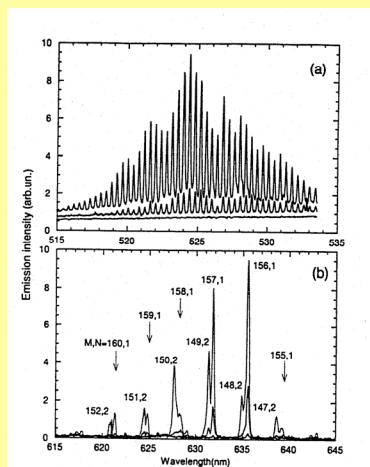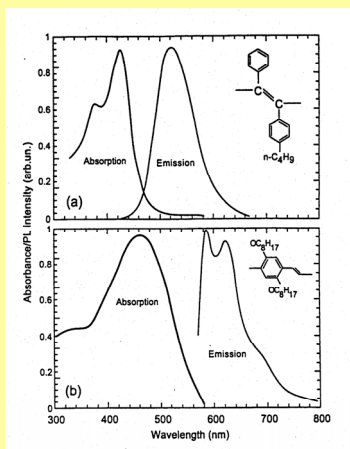
(a)   **Emission Spectra of a PDPA-nBu Micro-ring on a 125μm Optical Fiber at Different Excitation Energies. Energies from Top to Bottom are: 1.7μJ; 0.7μJ; and 0.6μJ**

(b)   **Emission Spectra of DOO-PPV Micro-ring on a 20μm Fiber at Different Excitation Energies. Energies from Top to Bottom are: 165 nJ; 90nJ; and 65nJ**

C A E F F

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Spherical Organic Cavity Lasers

DOO-PPV Microsphere
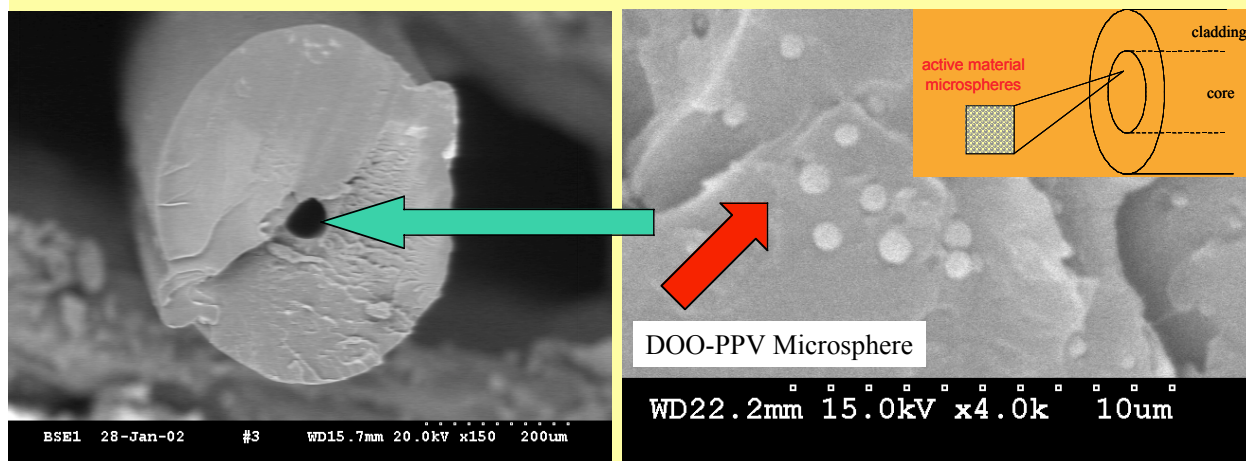
SEM of DOO-PPV / PMMA Blend Fiber

C A E F F

New Emissive Optical Molecules For Lasing, PL, and EL Applications

Synthesis of BEDOT-Q Derivatives
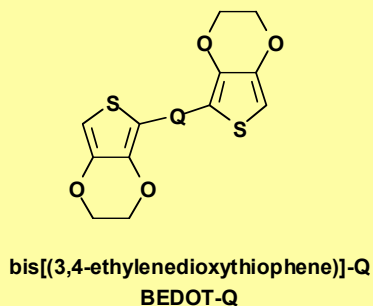
f	Q	
3.2% 3.4%		3-alkylthiophene **1** R = -CH$_2$(CH$_2$)$_2$CH$_3$ **2** R = CH$_2$(CH$_2$)$_6$CH$_3$
		cyanovinylene **3** R = -H **4** R = -OCH$_3$
7.1%		toluene
5.4%		thiazole
9.0%		1,3,4-oxadiazole

bis[(3,4-ethylenedioxythiophene)]-Q
BEDOT-Q

Pepitone, M.F.; Hardaker, S. S.; Gregory, R. V. *Chem. Mater.* **Vol 15, No. 2, 2003.**

C A E F F

938

New Emissive Optical Molecules For Lasing, PL, and EL Applications

Synthesis of 1,4-bis[1-cyano-2-{(3,4-(ethylenedioxy)thien-2-l}ethylene]benzene
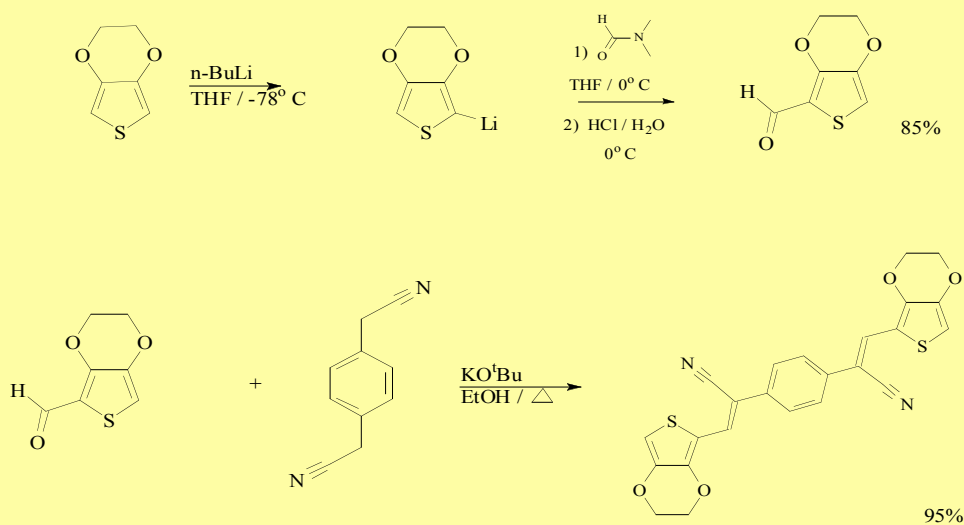
New Emissive Optical Molecules For Lasing, PL, and EL Applications

Cyclic Voltammagrams of BEDOT-Q derivatives
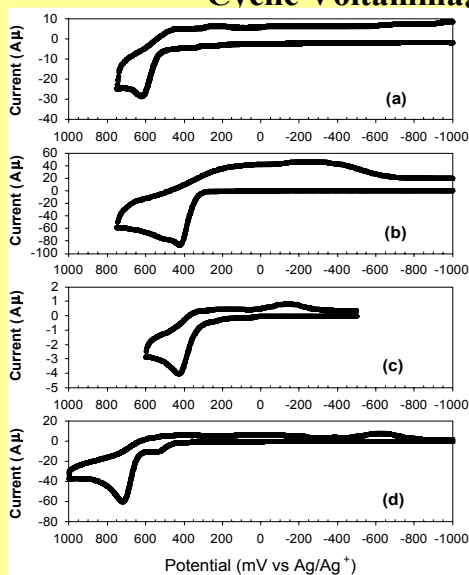
CV Deposition of BEDOT-TOL

Solvent: Acetonitrile

Electrolyte: TBAPF$_6$ (0.1 M)

Monomer Conc: 1 mM

Working Electrode: ITO

Reference Electrode: Ag/Ag$^+$

Auxiliary Electrode: Pt

Rate: 100 mV/s
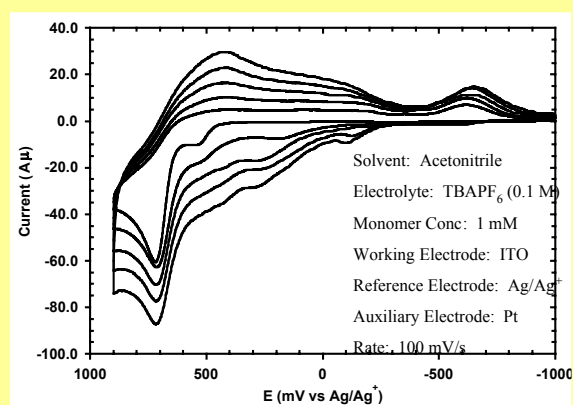
CVs of BEDOT-Q derivatives (1~10 mM, GCE working electrode, Ag/AgNO$_3$ reference, 100 mV/s, 0.1 M TBAPF$_6$). (a) BEDOT-TZ, (b) BEDOT-3BT, (c) BEDOT-3OT (50 mV/s), (d) BEDOT-TOL.

C A E F F

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Cylindrical Microrings
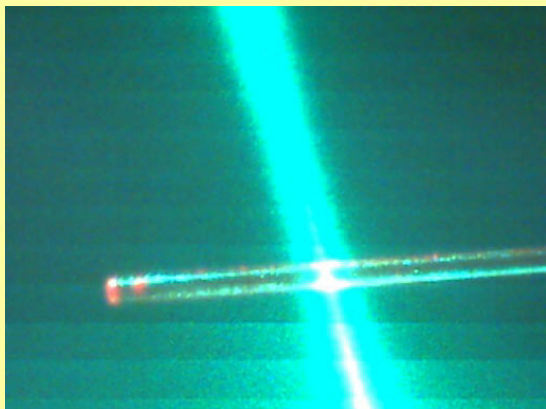
DOO-PPV microring on an optical fiber showing excitation energy in blue green and DOO-PPV red laser emission
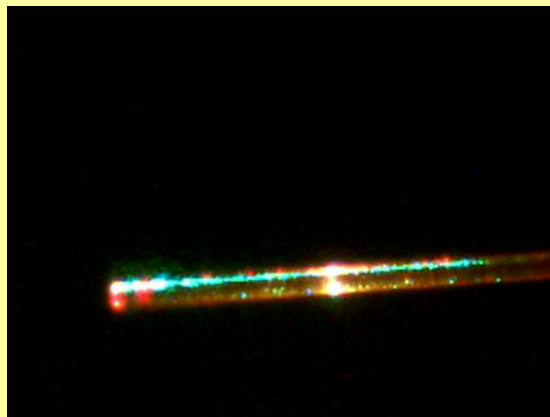
Several DOO-PPV laser emissions with excitation energy filtered out

C A E F F

Molecular Structural Changes

p-Polyphenylene vinylene
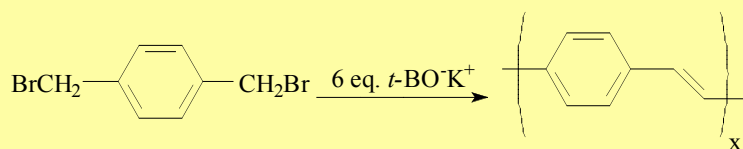
342nm Excitation
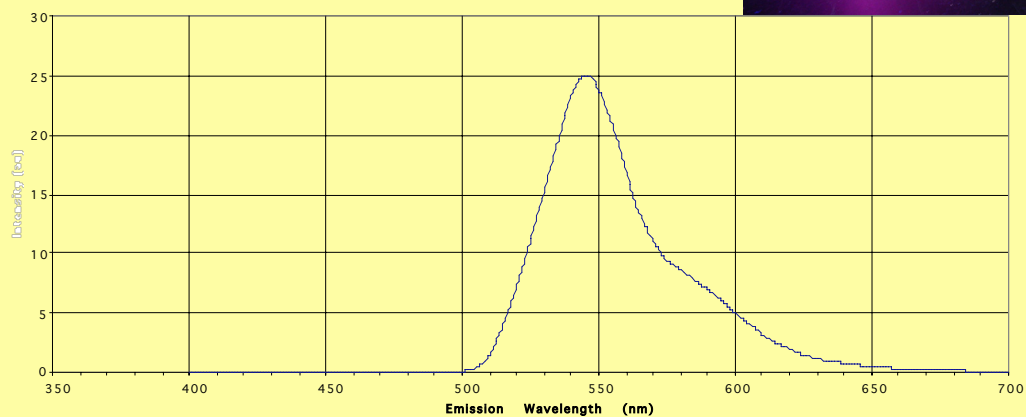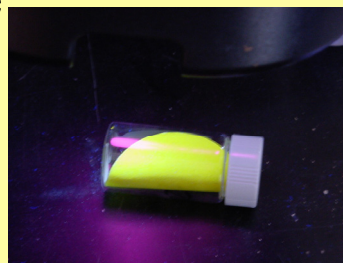
C A E F F

Molecular Structural Changes

m-alt-p-Polyphenylenevinylene

BrCH$_2$——CH$_2$Br
$\xrightarrow{\text{1. PPh}_3\text{, DMF} \\ \text{2. OHC, CHO, NaOEt}}$

342 nm Excitation

X

C A E F F

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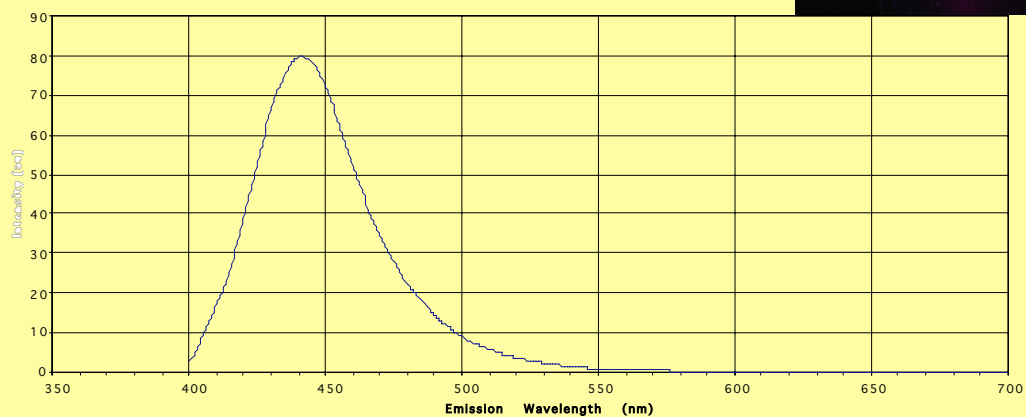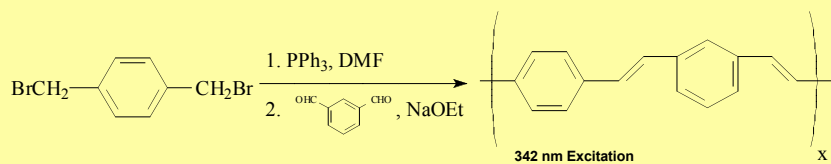
Molecular Structural Changes

Emission Comparison of *p*-Polyphenylene vinylene and *m-alt-p*-Polyphenylenevinylene
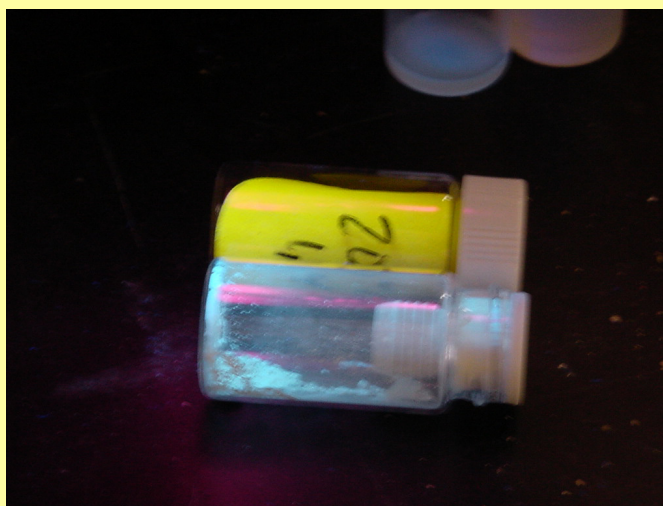
PPV

m-alt-**PPV**

C A E F F

Optical Spectrum Emitters

Multi Frequency High Efficiency Organic Emitters

hν
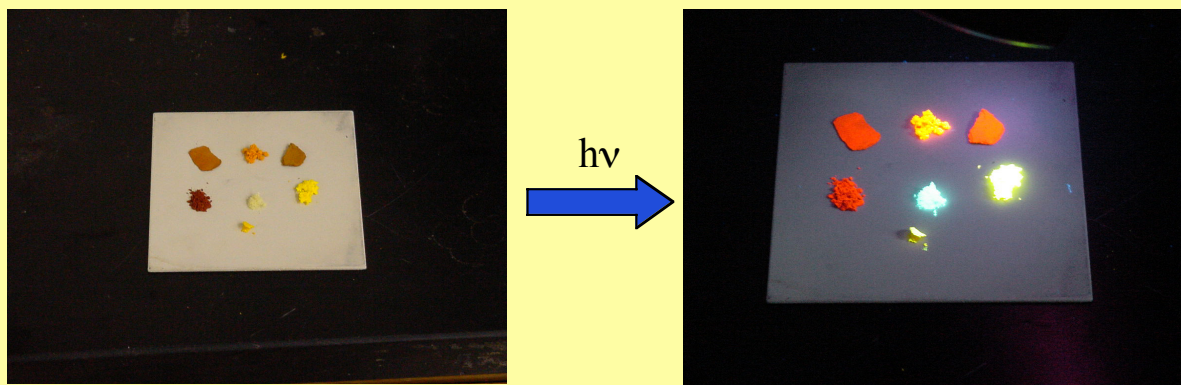
Recently synthesized organic photonic compounds for application to micro-ring and micro-sphere devices. Produced in our laboratories

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Additional Ongoing Work

- Micro-ring Fiber based all organic logic circuits

- *Ab initio* and semiempirical modeling of linear and non-linear optical properties.

- Development of "Chameleon Fibers"

- Development of molecular electronic and photonic polymeric systems

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Conclusions

- Structure is the critical link between processing and properties.

- Polymeric materials offer flexibility and significant weight savings.

- Development of micro-ring and micro-disk lasers for fiber and fabric based smart materials.

- Currently developing all-organic micro-ring logic circuits **(AND, OR, and Inverter gates already demonstrated).**

- Development of new materials for tunable lasers.

- Development of next generation smart materials will require multidisciplinary approach (synthesis, polymer processing and characterization, device engineering and design).

C A E F F

EXPERIMENTS IN X-RAY POWDER DIFFRACTION
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EXPERIMENTS IN X-RAY POWDER DIFFRACTION

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Abstract

Four experiments in x-ray diffraction covering basics, common and advanced techniques. Each builds upon the previous, ends with a capstone exercise asks the student to interpret a diffraction pattern that deviates greatly from was expected. Also, we use the diffractometer as the student's first analytical instrument. Is relatively easy to use and understand and helps teach data collection/sampling, the use of filters and standards, and factors effecting energy and angular resolution, all of which are common to many other instruments.

Keywords: x-ray diffraction, phase identification, quantitative analysis, crystallite size, residual stress

Equipment: x-ray powder diffractometer, ICDD's PDF database and PCPDFWin or equivalent

Prerequisite Knowledge: basic crystallography, principles of x-ray diffraction, production of x-rays, ICDD's PDF database, diffraction line broadening, Scherrer equation, Warren-Averbach analysis, Williamson-Hall method, residual stress, preferred orientation

Introduction: In a third-year course on the structure and characterization of materials half is devoted to diffraction methods, the subject of this paper. This portion of the course consists of four experiments and a final assignment all designed to teach principles and applications of diffraction and at the same time the structure of materials. The four experiments were designed as a coherent series that begins with the basics and then concentrates on major applications and related features of the diffraction pattern. These experiments are summarized in table 1 and are discussed in more detail in the paper.

In this course x-ray diffractometer is also used to introduce students to the world of advanced analytical instrumentation. The diffractometer is a relatively simple instrument and most of its main operational aspects can be illustrated using simple sketches showing the angles and distances between the source, sample and detector. From these simple sketches students can began to understand how filters are used to improve the incident radiation but at the expense of intensity, or changing the scatter and divergence slits to increase intensity but at the expense of 22 resolution. All of these are issues the student will encounter when they start using more complicated instruments such as SEMs, EDS systems, FTIR, and others.

Table 1. Summary of the Diffraction Experiments

Experiment	Diffraction	Structure of Materials
Introduction to X-ray Diffraction	Operation of a diffractometer, selection of parameters for diffraction scans, recognizing the basic features of the diffraction pattern (background, $k_{\forall 2}$)	Analysis of the diffraction pattern of quartz, examination of the (101) peak, peak overlap that produces the five fingers feature of this diffraction pattern
Quantitative and Qualitative Phase Analysis Using X-ray Diffraction	1. Line position and intensity as unique identifiers of crystalline phases 2. Absorption of x-rays	1. Use of diffraction patterns and the ICDD PDF database to identify a material in terms of its crystal structure 2. Relationship between relative intensities and concentration
Measurement of Crystallite Size Using X-ray Diffraction	Line-broadening due to crystallite size and microstrain, Scherrer and Warren-Averbach (Fourier) methods	Crystallite size and size distributions, characteristic averages in a distribution
Measurement of Residual Stress Using X-ray Diffraction	Shifts in line position due to residual stress (strain)	Nature of residual stress, biaxial stresses, relationship between changes in d-spacing and strain
Interpretation of Results from a Colleague's Diffraction Pattern	Incorrect peak intensities, peaks slightly displaced	Crystallographic texture, solid solutions

Experiment 1: The Basics of X-ray Diffraction

The goal of the first experiment is to teach the students the basics of x-ray diffraction well enough that they will be able to conduct the remaining three experiments largely on their own. The students are presented with the following scenario:

> "Your company is considering using x-ray diffraction for a number of research and quality control applications. You, being the one person with a materials science background, have been asked to visit a nearby facility to learn more about this technique. In your report you will describe the equipment, how an experiment is conducted, the major parameters for each experiment, what the form the data takes and the major features of the data, and the cost of performing a single diffraction measurement. Your report will be used to help determine how seriously your company gets into x-ray diffraction, and what your role in this initiative will be."

In preparation for this experiment the students are given the relative intensities of Cu-$k_{\forall 1}$, $k_{\forall 2}$, $k_{\exists}$ and W-$L_{\forall}$ radiation and the relative intensities of the (101) peak and the (212), (203) and (301) peaks (5-fingers region) of quartz and asked to use a spreadsheet to calculate these sections of the diffraction pattern. A Cauchy profile is used to give the peaks a realistic shape.

During the experiment itself the students are given a detailed tour of the diffractometer, showing them all of the major components and describing the practical aspects of the their of operation, especially those components that they can use to optimize their scan procedures. See figure 1. They then prepare the instrument for use and then run three data collection procedures on a sample of a quartz "stone". These scans illustrate how one might approach the analysis of a sample for which they are unfamiliar with. These scans are:

1. Quick scan over a wide range of 2θ, typically 5 to 90 degrees. This scan provides a low quality snap shot of the material's diffraction pattern.

2. Slower scan of the strongest peak, (101). This scan demonstrates how slower scans can produce higher quality results, and a careful look at the data shows how imperfect the raw diffraction data can be.

3. Slower scan of the 5-fingers region of the diffraction pattern. These results are compared to those from the calculated patterns and from the first scan.

In subsequent experiments the students will use essentially this procedure to get familiar with the diffraction pattern of their material and to select the parameters for higher quality and economical scan procedures.

The primary challenge of this experiment is learning a large amount of material quickly. In one laboratory session they must learn how to operate the instrument, collect data, and process and interpret the data. (See table 2.) Most students seem to do well with the operational aspect of this experiment as it is a very hands on and fairly concrete experience. The three data collection procedures only require 5 minutes each so they have ample opportunity to repeat them or try alternative procedures during the three-hour long laboratory session.

In their laboratory report the students must write about the diffractometer and its operation as well as their interpretation of the data. From a reading of these reports most students understand how to operate the instrument but have difficulty distilling their descriptions of the equipment and the procedure down to the essentials. In early implementations of this experiment many students had difficulty recognizing the significance of background counts, counting
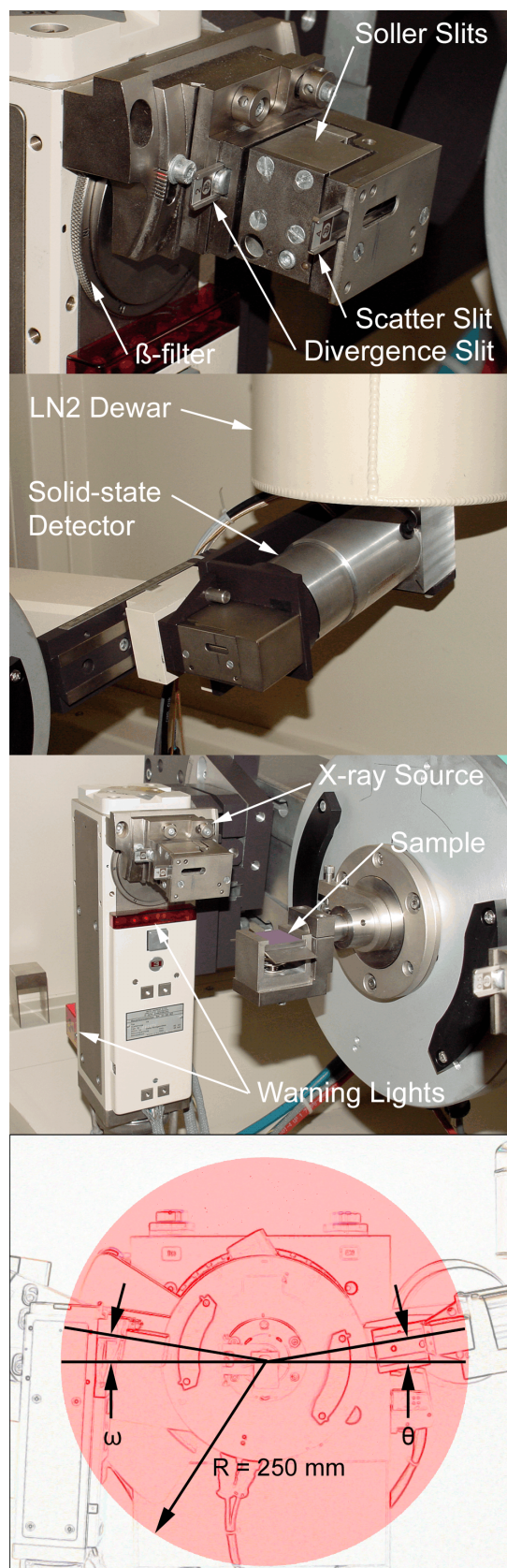
Figure 1 Views of the parts of the diffractometer the students are introduced to.

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statistics and parasitic peaks from $k_{\forall 2}$, $k_\exists$ and W-L$_\forall$ radiation. This problem was greatly reduced when they were asked to calculate sections of the diffraction pattern. See figure 2 for an example of the calculated pattern.

Table 2. Summary of Issues Covered in the First Experiment

Operation of the Instrument	
Source	Filament current, tube voltage, tube current, tube power, tube focus, the use of a nickel filter, control of axial divergence using soller slits and control of beam divergence using divergence and scatter slits.
Specimen	Position, flattness, roughness, preferred orientation
Detector	Control of axial divergence using soller slits, control of the receiving angle using receiving and scatter slits
Collection of Data	
22 Resolution	Relationship between step size and receiving slit size
Intensity	Increasing or decreasing intensity by changing the receiving slits or removing the filter, selection of sampling rate that produces acceptable counting statistics
Interpretation of the Data	
Background	Recognizing and stripping background
$k_{\forall 2}$	Recognizing and correcting for $k_{\forall 2}$ radiation
Peak Position	Use of a peak finder program to find the positions, width and intensities of the peaks

Experiment 2: Phase Identification and Quantitative Analysis

This experiment deals with what are probably the two most common applications of x-ray diffraction, phase identification and quantitative analysis. It focuses on the position and intensity of peaks and how these can be used to identify an unknown material. The students are given a small amount of a mixture of two powders and are asked to identify the components of the powder and to determine the concentration. Utilizing the lessons from the first experiment the students perform a quick preliminary scan to determine the 22 position and the intensities of the peaks. After a brief discussion among the students they agree on a scan rate and 22 range for a scan that will produce results suitable for quantitative analysis.
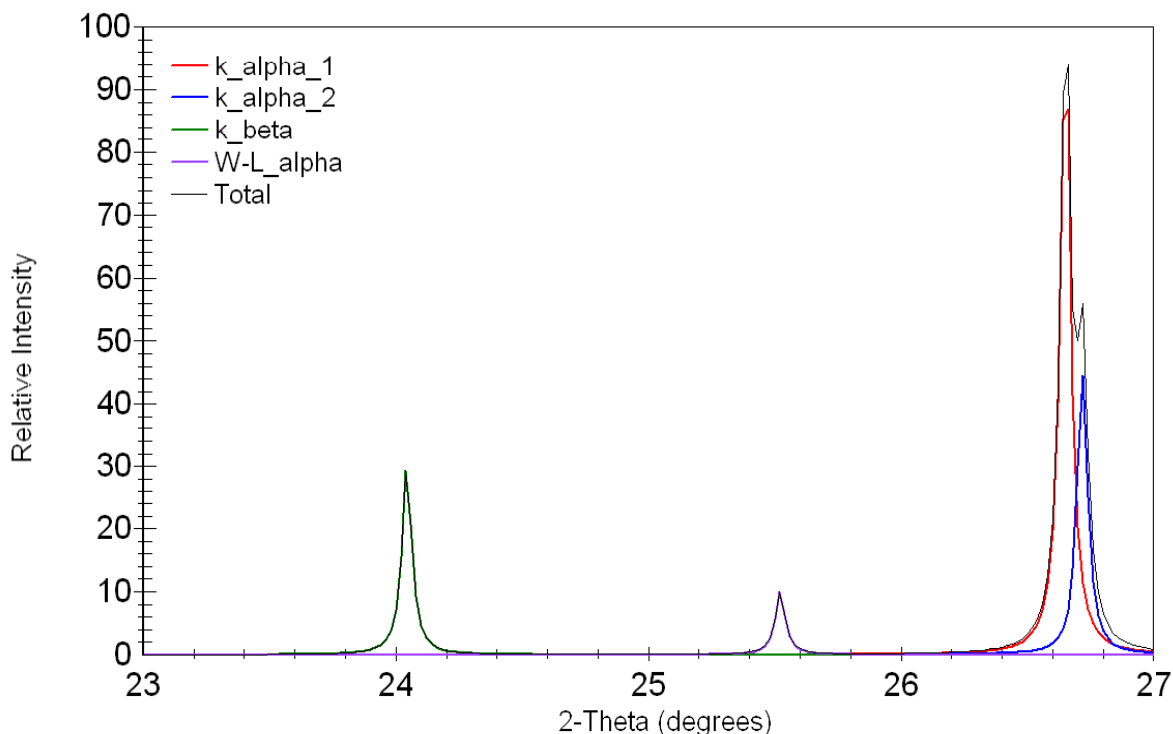
Figure 2 Calculated peaks for the (101) reflection of quartz for Cu-k$_{\forall 1}$, k$_{\forall 2}$ k$_{\exists}$ and W-L$_{\forall}$ radiation.

The phase identification analysis is performed using the diffractometer's search-match software. This procedure is very instructive, but it is not always successful. For instance, a match for only one phase may be made. The students then attempt their own search-match using the boolean search capabilities of the PCPDFWIN software. If they are still having trouble the instructor may give hints such as, the material is inorganic, include color in the search parameters, or limit the search to experimentally determined patterns. When they think they are done the student are asked how confident they are in their result, given that the elemental composition is not known.

The quantitative analysis is done using the diffractometer's software or a simple spreadsheet. Several methods are available, but all employ a reference intensity ratio (RIR) for each phase which is usually available in the PDF file. The software employs a matrix-flushing technique which can be used for mixtures containing any number of phases as long as all phases have been identified and the presence of any amorphous phase has been accounted for. For simple two-component mixtures the direct comparison methods can be used. The equation used in this case is

$$\frac{X_\alpha}{X_\beta} = \frac{I_{\alpha,i}}{I_{\beta,j}} \frac{I_{\beta,j}^{\mathrm{Re}l}}{I_{\alpha,i}^{\mathrm{Re}l}} \frac{RIR_{\beta,C}}{RIR_{\alpha,C}} \tag{1}$$

where X is the weight percent of the $\forall$ and $\exists$ phases, I is the measured intensity, I^{Rel} is the relative intensity from the PDF file or standard, the subscripts i and j refer to specific peaks in the patterns of each phase, and RIR is the reference intensity ratio for each phase relative to the intensity of corundum (RIR$_{\forall,C}$ = I$_{\forall}$/I$_{C}$). In this analysis the intensities of all peaks entered into a

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spreadsheet where peaks for the $\forall$ phase will be in columns and those for the $\exists$ are in rows. The ratios $X_\forall/X_\exists$ are calculated in the cells of the table. Each cell should give essentially the same result.

The success of the quantitative analysis are mixed. Often the correct result is obtained, but it is not unusual that they are not and there are a number of good reasons why this may be the case in the teaching laboratory. These difficulties, listed in table 3, were discussed in class but were probably not appreciated until the results were analyzed. Skill and care in preparing the samples is critical to this type of analysis.

Table 3. Common Sources of Difficulties in the Quantitative Analysis Experiment

Problem	Description	Remedy
Mixing of the sample	One phase may sink to the bottom of the bottle or rise to the top during sample preparation	Use methanol or another binder to temporarily glue the particles together
Preferred orientation	The intensities of the peaks will not be the same as for a truly random powder.	This problem can be minimized by using the best sample preparation/ loading procedure. Back-loading sample holders tend to work better in this respect.
Accuracy of published RIR values	ICDD acknowledges that all published RIR (I/I$_C$) values may not be as accurate as they could be.	Determine your own RIR values. This will help with the lack of availability of RIR values of your material.

Experiment 3: Crystallite Size in Measurements Using X-ray Diffraction
This experiment gives the students a chance to work in nanotechnology. It also deals with the width and shape of diffraction peaks, demonstrating that there is much more information in a diffraction pattern than what was considered in the previous two experiments.

Two approaches have been in this experiment. One involves a combination of the Scherrer and Warren-Averbach methods as described by Krill [1]. More recently the method described by Suryanarayana and Norton [2] has been used.

In the Scherrer analysis experiments the crystallite size is given by

$$L = \frac{k\lambda}{B_{\frac{1}{2}}\cos(\theta_B)} \tag{2}$$

where L is a characteristic crystallite size, 2_B is the Bragg angle, $\mathcal{S}$ is the wavelength of the x-ray and K is a unit cell geometry dependent constant whose value is typically between 0.85 and 0.99. $B_{\frac{1}{2}}$ is the full-width-half-max of the peak after correcting for peak broadening which is caused by the diffractometer. One way to represent $B_{\frac{1}{2}}$ is

$$B_{\frac{1}{2}}^2 = B_{obs}^2 - B_m^2. \tag{3}$$

where B_{obs} is the measured peak width and B_m is the beak broadening due to the machine.

The Warren-Averbach method is based on a Fourier analysis of the diffraction peak. The measured peak profile $h(s)$ is seen as the convolution of the function for the pure peak profile $f(s)$ and the function for the instrumental broadening $g(s)$

$$h(s) = g(s) \otimes f(s) \tag{4}$$

where s/(2sin2)/8. This can be represented by the product of the Fourier transforms for instrumental broadening and the pure peak profile

$$\rangle(h) = \rangle(g) \cdot \rangle(f). \tag{5}$$

Processing the data involves calculating the Fourier transforms $\rangle(h)$ for the measured pattern, $\rangle(g)$ obtained from the analysis of a line-width standard such as LaB_6, and then solving for the Fourier transform of the pure peak profile $\rangle(f)$. The result is

$$\rangle(f) = \sum_{L=\infty}^{\infty} A(L) \cos[2\pi(s - s_0)L] + B(L) \sin[2\pi i(s - s_0)] \tag{6}$$

where $A(L)$ and $B(L)$ are the cosine and sine coefficients and L is the length of a column of unit cells perpendicular to the diffracting planes. A plot of $A(L)$ versus L is used to determine the characteristic crystallite sizes and lattice microstrain. If two peaks in the same family are used in this analysis then the contribution of microstrain can be eliminated.

Both methods yield a measure of crystallite size, but they have different values since they are actually different characteristic averages in a distribution of sizes. The Scherrer method yields the volume-weighted average $<L>_{Vol}$ while the Warren-Averbach methods yields the area-weighted average $<L>_{Area}$. Assuming the crystallites are spherical these column lengths can be converted to characteristic average diameters $<D>_{Area}$ and $<D>_{Vol}$. With two points in the same size distribution, and assuming a log-normal size distribution, it is not difficult to determine the width Φ and median of the distribution and then to plot the crystallite size distribution as shown in figure 3.

In the second method the Scherrer size $<L>_{Vol}$ is determined independent of microstrain by using the Scherrer equation on a number of peaks. In this case broadening due to size and strain is given by

$$B_{\frac{1}{2}} = B_{Size} + B_{Strain} \tag{7}$$
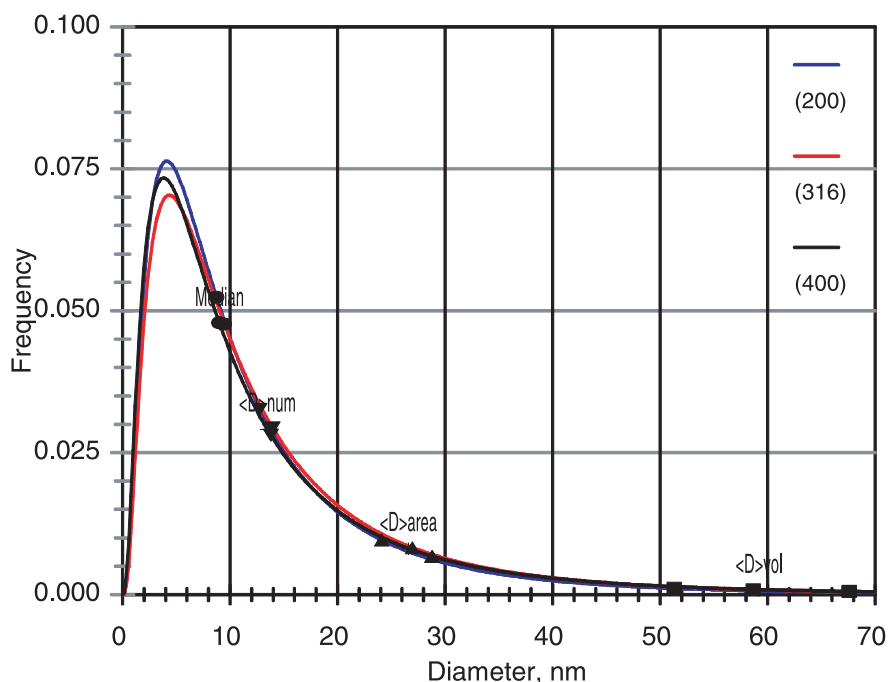
Figure 3 Final log-normal distributions for three peaks in the diffraction pattern of anatase.

where B_{Size} is given by the Scherrer equation and B_{Strain} is given by

$$B_{Strain} = \eta \, sin(\theta) \tag{8}$$

where θ is the microstrain. From equations 2 and 8 we get

$$B_{1/2}cos(\theta) = \frac{k\lambda}{<L>_{Vol}} + \eta sin(\theta) \tag{9}$$

where $B_{1/2}$ is the geometric mean of B_{Size} and B_{Strain}. The value of θ is determined from the slope of a plot of $sin(2\theta)$ versus $B_{1/2}cos(2\theta)$ and the intercept yields the value of $<L>_{Vol}$.

The experimental procedure begins by creating a line-width standard by performing a careful scan of NIST's line-width standard (LaB_6). This is usually done in advance and the results are given to the students. The students analyze nanocrystalline powders such as Al_2O_3 or TiO_2 for which SSA (specific surface area) sizes are in the range of 24 to 40 nm. Scans on the nanocrystalline material are performed as in the previous exercises, but the goal here is to obtain quality data from one or two peaks if the Scherrer/Warren-Averbach analysis is used or for a number of peaks if the second method is used.

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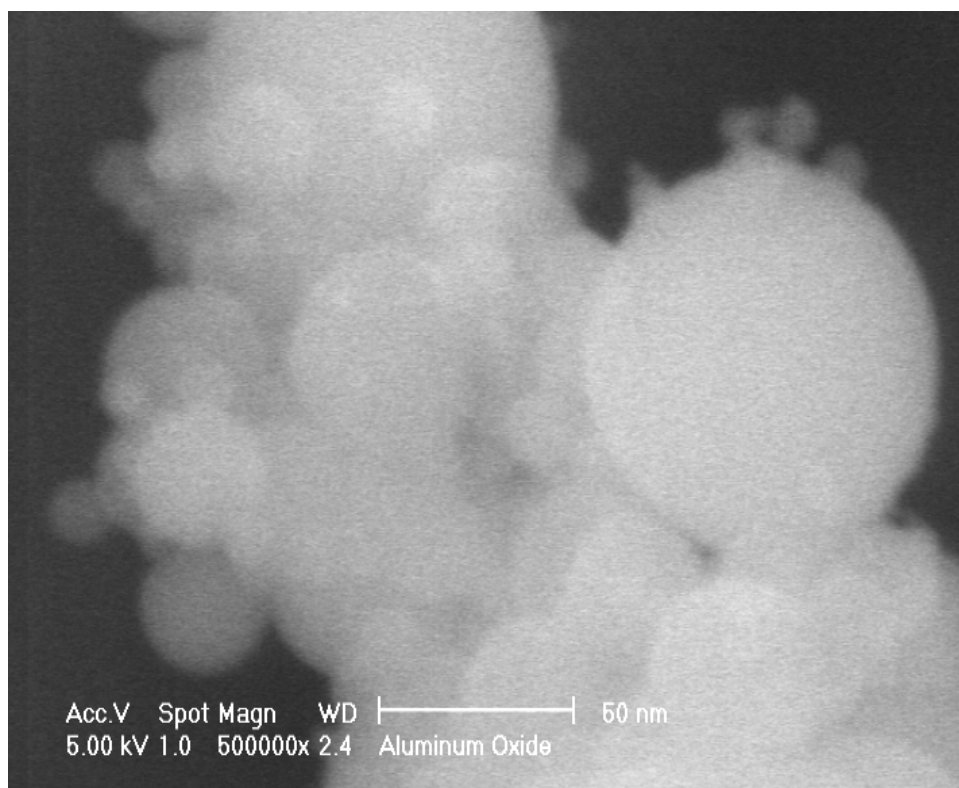
Figure 4 FEG-SEM image of 32 nm (SSA method) aluminum oxide powder. A distribution of sizes, from under 5 nm to over 50 nm, can be seen here.

The results are generally very good. Crystallite sizes are similar to those given by the manufacturer. The differences seen are considered in light of the fact that the SSA method is a particle size technique that is derived from the density and specific surface area of the powder. Also, the values obtained from the x-ray diffraction measurements are two different characteristic averages in a distribution, so the results must be viewed in the context of a distribution of crystallite sizes.

The diffraction method is but one of many particle size measurement techniques and not all techniques give the same answer because size will be defined differently. Different sizing techniques may be used depending on the nature of the sample and the application. Size defined in terms of area per volume may be more important in a kinetics study while size defined in terms of average cross-section may be more important in a mechanical properties application.

Related to the issue of different methods yielding different sizes is the important distinction that the students must make here, that particle size and crystallite size are different things altogether. A particle may be an aggregate of grains and crystallites and even a single crystal particle may be twinned. The SSA method, for instance, may not be able to make these distinctions while these x-ray methods do.The final aspect of this experiment is that size is something one should be able to see, without the complicated and seemingly abstract process used in this experiment. Are the sizes, and the size distribution, determined here the same as what one would see in a picture of the powder? Are the particles spherical as was assumed? The students are shown a high-resolution SEM image (figure 4) so that they can answer these questions. The final lesson in this experiment is, therefore, that when possible complementary techniques should be used.

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Experiment 4: Measuring Residual Stress Using X-ray Diffraction
There are a number of reasons that the measured d-spacing might be slightly different from those published in the PDF database. Sample purity is one possibility, strain is another. The ability to measure small changes in d-spacing using x-ray diffraction allows one to also measure strain, and using the appropriate elastic constants one can estimate the applied or residual stress. In this experiment the students measure the biaxial residual stress in a steel spring and in the process are reminded that the origins of macroscopic stress, which is due to the restoring force acting between the atoms, are found on the atomic scale. The procedure employs the $\sin^2 P$ method described in Cullity [4]. The biaxial stress in an arbitrary direction N in the surface of the sample is given by

$$\sigma_\phi = \frac{E}{(1+\nu)\sin^2 \psi} \frac{d_i - d_N}{d_N}$$
(10)

where E is Young's modulus, ν is Poisson's ratio, d_i is the d-spacing measured at a tilt angle P and d_N is the d-spacing measured at P=0. This method involves scanning one peak several times but each time the sample is tilted an angle P in the plane of the diffractometer. In scans made at each angle from 0 to $\forall$P the peak position will change slightly due to the biaxial strain. When these peak shifts are plotted and a least squares fit of the data is performed one obtains the stress from the slope of the line. Typical results are shown in figure 5.

The procedure used in this experiment involves first performing these measurements on a strain-free iron powder. This is done to verify the instrument's alignment and should yield a stress close to 0 MPa. These measurements are done before class and the results are shown to the students to allow them to see sample results and to see that the instrument is operating properly. The students then work out the parameters they will use for the measurements on the spring, keeping in mind the fact that the scan of the iron powder took several hours and that they had to complete the assignment in three hours. They are also advised to use larger receiving slits since intensity, and therefore counting statistics will be a problem while 22-resolution is not a major concern.

This experiment works very well if the instrument alignment is good. There are no problems with sample preparation since it is a solid piece of steel and sample displacement errors are at least constant because the sample was loaded into the sample holder once. In years when we know the alignment is not good enough we run the experiment as a hands on demonstration and the students are given the good results from a previous year.
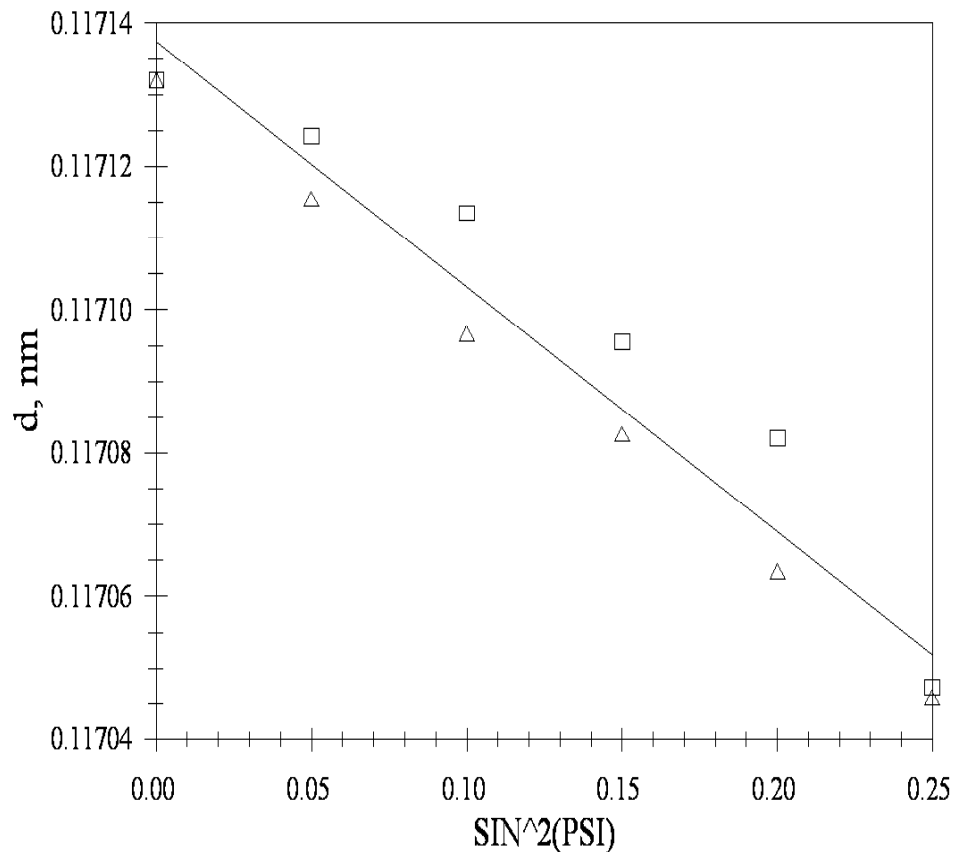
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Figure 5 Experimental plot of the change in interplanar spacing of the (211) diffraction peak of a spring steel as a function of the square of the specimen tilt angle (psi). The shift in d values is a result of the residual stress in the surface of the steel sample as a result of its manufacturing process. The triangle symbol data represent negative values of psi (specimen tilted towards the x-ray source) and the square symbol data represent positive values. The slope of the plot indicates a compressive stress of 506 MPa.

Final Problem:

To challenge the students with a completely new problem, one that is not in the text book, and to put them in the situation where their knowledge and experience are called upon, they are presented a simulated real-life problem. These problems may concern the feasibility of performing a certain analysis or requiring their expert opinion in interpreting the results of a colleague's analysis.

In one such case the students are briefed on a recent trend to find replacements of Pb-Sn solders. In this case the Bi-Sn system is being evaluated using a number of electrical, mechanical properties tests and materials characterization techniques. For the x-ray diffraction analysis sample were melted on a smooth glass plate and scanned using the normal procedure. When the results came in your colleague panicked. A number of peaks were missing, the intensities of the peaks that were present did not match those in the PDF files, and some of the peaks shifted slightly. Even more confusing, when the surfaces of the samples were ground using 320 grit carbide paper many of the missing peaks reappeared. Figure 6 shows these results the students would be presented.
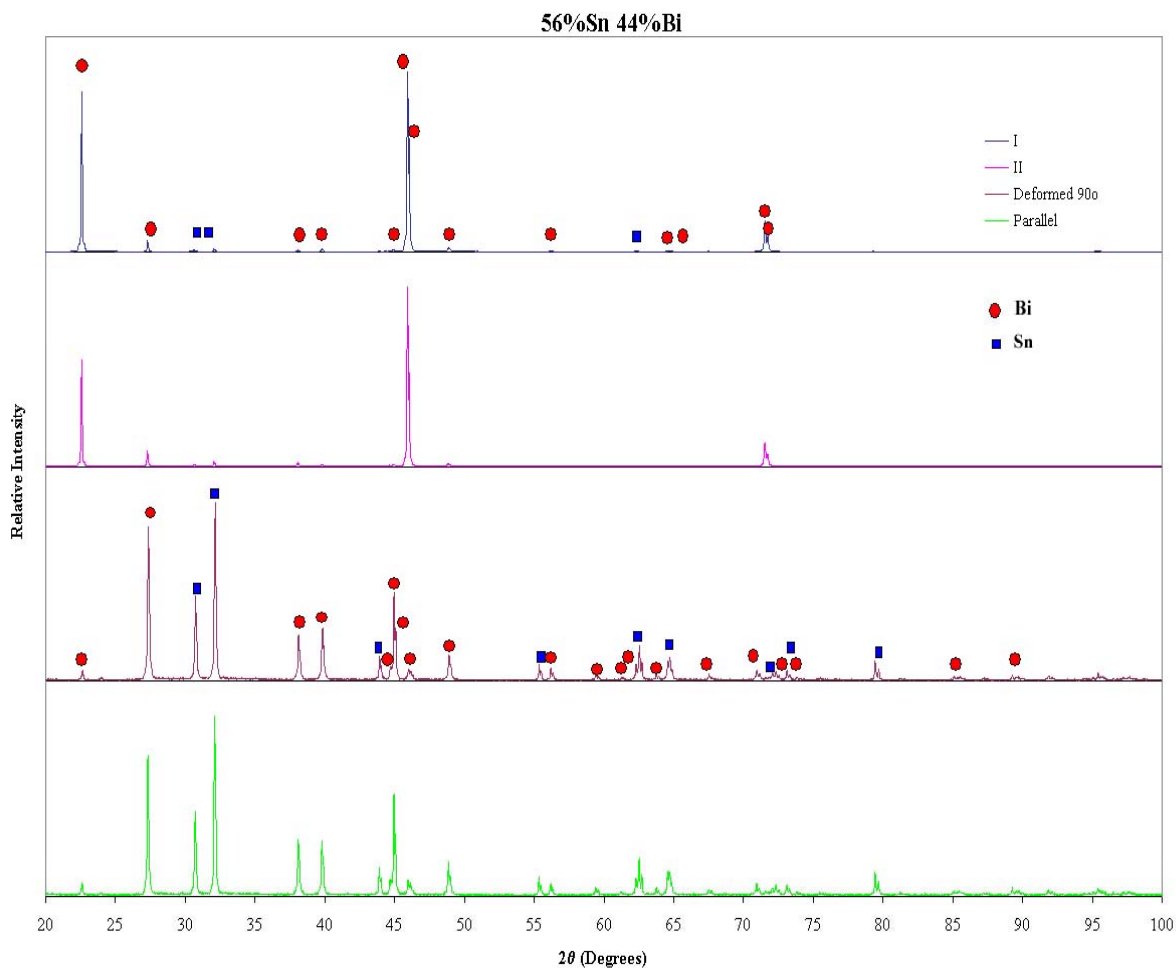
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Figure 6 The top two diffraction patterns are for two samples of 44/56 Bi/Sn solders which had been cooled on a piece of glass. The red dots mark the peaks of the Bi-rich phase and the blue squares indicate the positions of the Sn-rich phase. The bottom two patterns were for sample I that had been ground using 320 grit SiC paper parallel and perpendicular to the direction of the x-ray beam.

The students should be able to figure out that the original sample exhibited a high degree of preferred orientation. Cooling from the melt most likely produced a columnar-like structure similar to that seen in castings. The peak displacements, if not due to instrumental errors, were due to the solid solubility. The peaks for the Bi-phase should show greater shift than the Sn-phase due to the higher solubility of Sn in Bi. Finally, grinding the sample changed the orientation of grains near the surface. Grinding deforms material near the surface and since Bi and Sn have a high absorption coefficients x-rays are unlikely to reach the material below this deformed layer.

Discussion:
When this course was first set up the experiments employed represented a sampling of the types of analyses one could do using x-ray diffraction. Over several years these have been refined so that they work as a coherent series that takes the student from the basics of instrument operation

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and data analysis to a point where they should have a working knowledge of x-ray diffraction and its applications. The guiding principles and objectives in developing these experiments are:

$ The experiments must use skills and knowledge from earlier experiments to reinforce this knowledge and to develop the student's confidence.

$ Each experiment should add another dimension to the student's knowledge of x-ray diffraction and the structure of materials. For example, one experiment might emphasize peak intensity (composition) and another may emphasize peak shape (crystallite size).

$ Every experiment must feature a *structure of materials* topic. This is not a physics course on diffraction phenomena.

$ In the end the student should have a functional knowledge of x-ray diffraction and will be ready for independent work or to learn another instrument.

Table 4 summarizes the lessons taught in each experiment and how this knowledge is employed in each succeeding experiment. The "Old Knowledge" column lists knowledge and skills that the students had acquired in previous experiments. Not listed, but obvious, is that everything the students learned in the first experiment is essential to the other three and the final exercise.

By working to present these experiments as a coherent series we have seen an increased efficiency and effectiveness. This comes from a degree of overlap in each experiment and the fact that the same instrument is used each week. For example, students come to the first experiment not knowing what to do come to the second experiment ready to fire up the diffractometer and get everything ready even before the other students have arrived. This not only builds confidence but it allows everyone to concentrate on the new material.

One criticism of this approach is that the students do not get to work with many of the other instruments that are available, such as the x-ray radiography system, acoustic microscope, electron microscopes, EDS and EBSD, thermal analyzers, and others. The rebuttal argument is that one cannot really accomplish much by spending a little time with many different tools, that this is more like viewing the exhibits in a museum than teaching someone how to actually do something. Actually, one day is set aside for brief demonstrations of these instruments, but the objective is more to provide exposure and to generate interest. The strongest arguments for narrowing the scope of the course, in this case by concentrating on one instrument, is that the students build a body of knowledge of how one instrument works and how to design and carry out an analysis. In the end the students are much better qualified to start learning other materials characterization techniques, much like learning one musical instrument or foreign language makes it easier to learn others.

Table 4. Summary of the principal lessons taught in each experiment.

Experiment	Old Knowledge	New Knowledge or Result
Introduction to X-ray Diffraction (The Basics)	Knowledge of basic crystallography and diffraction, from lectures	1. Instrument and operational issues 2. Data collection strategies and compromises that are made 3. Data interpretation and basic pattern processing
Quantitative and Qualitative Phase Analysis Using X-ray Diffraction (Whole Pattern, Intensity)	All knowledge from the first experiment	1. Search-match using the PDF database 2. Details of peak intensity 3. Absorption coefficients
Measurement of Crystallite Size Using X-ray Diffraction (Peak Shape)	1. Phase identification using the PDF database (i.e., anatase/rutile in TiO_2) 2. Data collection strategies emphasizing counting statistics	1. Mechanisms of peak broadening 2. Size distributions 3. What does one really mean by particle and crystallite size? 4. Every feature in the diffraction pattern contains information that can be mined
Measurement of Residual Stress Using X-ray Diffraction (Peak Shifts)	1. Data collection strategy that emphasizes intensity at the expense of 22 resolution	1. Reasons the peaks may be displaced 2. Relationship between macroscopic strain and distortion of the crystal structure 3. Applications of x-ray diffraction are not limited to crystallographic analyses
Interpretation of Results from a Colleague's Diffraction Pattern (Working Knowledge)	1. Familiarity with the Bi-Sn system from an experiment done in another course 2. Synthesis of all of the above	Student finds he/she does or does not have a functional knowledge of the subject.

Conclusions:
The experiments used in the original course are the same as those in the current version. The difference is the order in which they are taught and how the teaching knits them together. The course flows from one experiment to the next and the instructor points out what knowledge from the previous experiment will be valuable in the next and what new dimension the upcoming experiment will add to that knowledge. The instructor basically connects the dots for students, many of which have become accustomed to thinking of laboratory courses as a series of disconnected assignments for whom the goal is reduced to getting a good grade. Our goal is to help them build a body of knowledge, confidence in their skills, and the acquisition of a recognizable skill they can carry with them to their future study and employment.

At the end of the quarter the students are told that the instruction they received in the first experiment is nearly identical to the operator training that our researchers receive. They are also told that what they learned by doing the remaining experiments makes them more qualified on this instrument than many of our graduate students. The course concludes with an invitation to

take advantage of what they have learned, that the diffractometer is now available to them for use in future course work, projects or even undergraduate research.

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3. V.J.Leppert, S.H.Risbud, and M.J.Fendorf, Phil. Mag. Letters, v.75, n.1, pp.29-33, (1997).
4. B.D.Cullity, Elements of X-ray Diffraction, 2nd edition, Addison-Wesley, Reading, Mass., pp.436-441, (1967).

Biography:

Michael L. Meier received his B.S. in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph.D. (1991) in Materials Science and Engineering from the University of California, Davis. After a two-year post-doctorate position at the Universität Erlangen-Nürnberg in Erlangen, Germany he returned to UC Davis where he is now the director of Materials Science Central Facilities and is also developing the laboratory teaching program.

Kit Foo is a graduate student in materials science working on amorphous aluminum alloys and metal matrix composites. He got his B.S. in materials science from Northwestern University and his M.S. from U.C. Irvine. He was also the teaching assistant for the x-ray diffraction portion of this course last winter.

Rita Kirchhofer is an undergraduate student majoring in double-majoring in materials science and in mechanical engineering. She is entering her senior year and is participating in Materials Science Central Facilities' Undergraduate Internship in Materials Characterization where she is working with x-ray diffraction, x-ray radiography, acoustic microscopy, optical microscopy and scanning electron microscopy and EDS, assisting in summer outreach programs and participating in several course development projects. She was also a student in this course last winter.

DECISION-MAKING BY WEIGHTED-RATING
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Edward L. Widener

Decision-Making by Weighted-Rating

Edward L. Widener

Purdue University- Mechanical Engineering Technology Department

West Lafayette, IN 47906

Key Words: materials selection, properties, and processes

Prerequisite Knowledge: Basic understanding of metals, ceramics, polymers, composites

Objective:
Souvenir letters (6) which spell PURDUE are to be stored in a rack (acrylic or wood) and used as a desk decoration, or individually as paper-weights. Each letter would be formed as a block, 1" x 1" x 1", having attractive color and weight. But low cost and high price are pluses. Casting in the MET142 Foundry Lab was our preferred process to make the 5 prismatic shapes, for 6 letters.

Abstract: Our PURDUE LETTERS project involved several MET/CIMT classes in the Mechanical Engineering Technology Department. "Applied Materials & Processes," MET 141, included decision-making by weighted-rating calculations. My fall '99 class found the logical material for casting block letters is "Yellow Brass."

Introduction: Everybody make decisions. Where to eat? What car or house to buy? Whom to marry? Or how to select material for a new product? If trivial, we flip a coin. Serious matters get a "T-chart," checking pros (+) and cons (-) for each choice. S oon we make bigger checkmarks for major factors, the start of weightings; see TABLE I. Really important decisions, with a dozen options, deserve more formal treatment. Hence our "weighted rating" by tabulation and calculation is prescribed; see TABLE II.

Tabulation:
A) Candidates, as proposed, were listed vertically. We started with Acrylic/ Aluminum/ Brass/ Cast Iron/ Copper / Gold /Stainless/ Steel/ Sterling/ Titanium
B) Requirements (our "Must" list) included "Groovy Color" and "Hefty Weight." As "Go-Nogo" criteria, these scratched some candidates and saved calculations.
C) Desired properties (our "Wish" list) were run horizontally. Our nine included Low cost/ High density/ Pretty color/ Color fastness/ High Hardness/ Corrosion resistance/ Smooth surface/ Heat resistance/ Impact toughness.
D) Each property was "weighted" for importance, and each candidate was "rated" accordingly, on a scale of 1-10.
E) The "weighting" of each property was multiplied by the "rating" of each candidate, giving "points" to be totaled for each candidate. The top point-getter is our selected candidate.
F) Weights and rates (from 1-10) are typical; remember Mohs scratch-test for hardness has diamond as 10. However, percents from 1-100 may be better for more complex lists; or use a simple ranking (say 1-2-3) for shorter lists.

G) When each candidate's "total points" are divided by the sum of "weightings," the quotient is between 1-10. Thus one integer means 10% difference, which is significant.

H) Any difference less than 1% probably means reassess our weightings and ratings, perhaps add candidates and properties.

I) In case of a tie, no worry. Either candidate is acceptable.

References:
1. DeGarmo, E. Paul, et al, "Materials and Processes," 8th ed, p. 240, Prentice Hall, 1997, Upper Saddle River, NJ.
2. Jacobs, J.A. and Kilduff, T.F., "Engineering Materials Technolog y," 4th ed., Prentice-Hall, Upper Saddle River NJ.
3. Parker, S.P., (ed), "Dictionary of Scientific and Technical Terms" 5th ed., McGraw- Hill, New York, NY, 1994.

Biography:

Professor Widener has taught at Purdue University since 1978, concentrating on mechanics, materials, recycling, and communicating. Ed was in Malaysia from April 1995- June 1996, teaching Metals Lab for new technology teachers.   Memberships include ASEE, ASME, ASM, ISA, and TAPPI. A registered P.E. in New York and Indiana, he was ABET-accreditation visitor from 1983-1990; and NSF lab grants reviewer in 1989 and 1990. Between 1994-1997 he had night classes in Indianapolis, IN (IUPUI) and Danville, IL (Jr. College). Degrees from Purdue are BS '49 (physics) and BS '51 (ME); his MSEM '62 (Hydraulics) is from University of Kansas. Between 1952-1978, Ed was a process or project engineer for Continental Group, Baker-McHenry-Welch, Kimberly-Clark, E.I.DuPont, Union Carbide, and U.S. Steel. In WWII he was U.S. Navy s2/c, aboard light cruisers Vicksburg and Astoria.

Table I

<u>Decision By T-Chart</u>
"Who Will Be My Valentine?"

Candidate #5

(+) Pros	(-) Cons
Shaves Daily	Ugly
Short Memory	Can't Cook
Doesn't Snore	Bad Housekeeper
Inherits 1 million	Bad Driver
dollars, tax free,	Bad Temper
next year	Whiner
	Lazy
	Bad Breath
	Dumbell

Here's Your Basic
"Weighted Rating"
<u>For MET 141</u>

TABLE II												

Material Selected By Weighted Rating:

	MUST		WISH LIST									POINTS
Candidate	Groovy Color	Hefty Mass	Low Cost	High Density	High Color	Color Fast	High Hardness	Low Corrosion	Smooth Surface	Heat Resist	Impact Tough	Σ WT X RT
	Go No	Go No	WT X RT	WT X RT	WT X RT	WT X RT	WT X RT	WT X RT	WT X RT	WT X RT	WT X RT	per Σ WTS.
1. Acrylic	OK	X										
2. Aluminum	OK	X										
3. Brass	OK	OK	7 X 5	8 x 6	7 x 8	5 x 7	6 x 7	7 x 6	6 x 7	4 x 7	7 X 7	6.61
4. Cast Iron	X	OK										
5. Copper	OK	OK	7 X 6	7 X 6	7 X 7	7 X 7	7 X 3	7 X 6	7 X 7	7 X 6	7 X 5	5. 88
6. Gold	OK	OK	7 X 1	7 X 10	7 X 8	7 X 7	7 X 3	7 X 10	7 X 7	7 X 9	7 X 5	6.65
7. Stainless	OK	OK	7 X 5	7 X 6	7 X 6	7 X 5	7 X 6	7 X 8	7 X 8	7 X 7	7 X 7	6.44
8. Steel	X	OK										
9. Sterling	OK	OK	7 X 2	7 X 7	7 X 6	7 X 6	7 X 5	7 X 6	7 X 7	7 X 6	7 X 6	5.65
10. Titanium	OK	X										
* Conclusion: Brass (6.61) & Gold (6.65) are Finalists												
But, Gold is high-melting and hard to guard.												
Thus, Brass is our Winner!												

ELECTRIC-POWERED RADIO-CONTROLLED AIRPLANES AS FLYING COMPOSITES
L. Roy Bunnell

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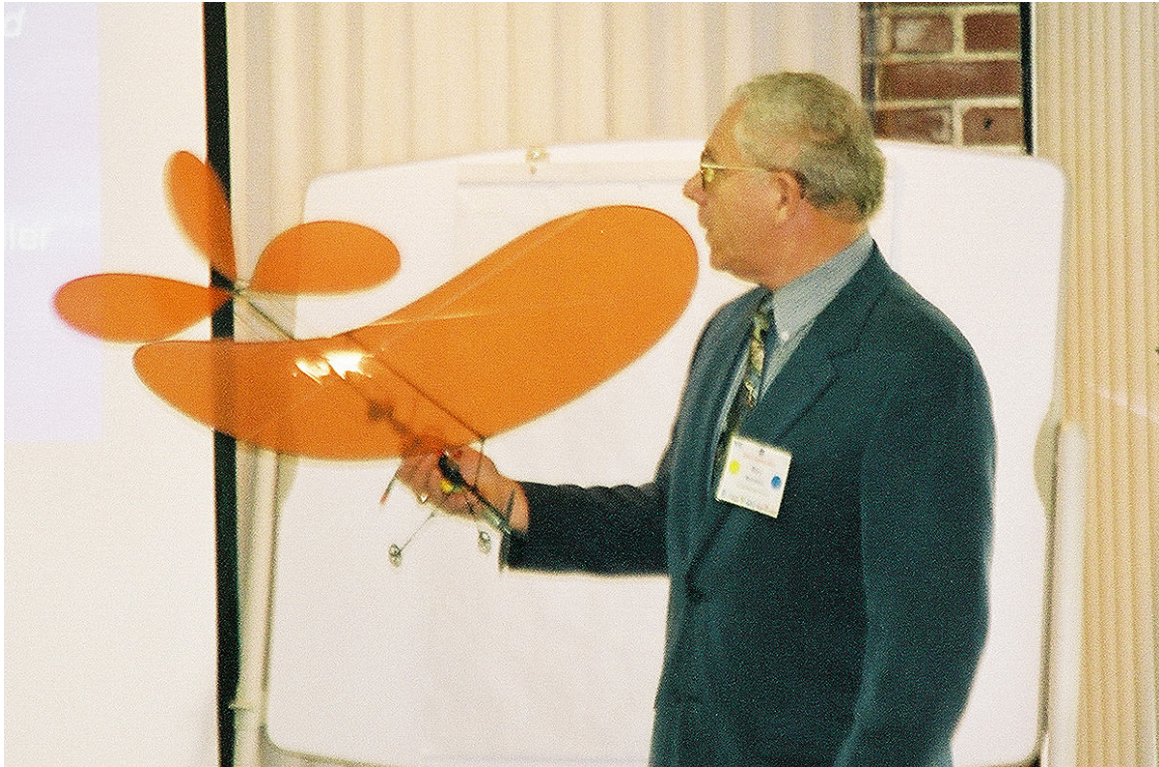
L. Roy Bunnell

ELECTRIC-POWERED RADIO-CONTROLLED AIRPLANES AS FLYING COMPOSITES

L. Roy Bunnell
Southridge High School
Kennewick, WA

Key Words:
Model Airplanes
Electric-Powered Flight
Composites
Radio Control

Prerequisite Knowledge: Basics of composites, some experience building model airplanes.

Objectives: Demonstrate electric-powered flight, illustrate the crucial role of composites in its success.

Equipment and Materials: "Butterfly" or similar Park Flyer airplane, Northeast Sailplanes, Inc; RC radio equipment with micro receiver and two nano servos; Nickel Metal Hydride Battery, 7-cell, 250 mAH; (Depending on experience) Flight Simulator for PC from Great Planes; 5-amp speed control; Battery Charger, all available from Tower Hobbies, Champaign, IL. There are several other vendors; all are pretty competitive.

Introduction: When one thinks of radio-controlled model airplanes, what generally comes to mind are large, noisy and fast models that are expensive, difficult to build and pilot, and impossible to fly in small spaces. Recent advances in composite materials, electronic miniaturization, electric motors and batteries have spawned a quiet revolution in radio-controlled flight, and aircraft are now available which can be flown in a (large) front yard or a school gymnasium. Many of these aircraft don't require the many hours of building time of their larger, engine-powered cousins; these models are designated as ARF (almost ready to fly) and can be completed and ready for flight in less than 5 hours, even for a novice. Due to the use of ever-lighter composite materials and smaller, lighter radio gear and power systems, these airplanes have a very low wing loading, often less than 5 ounces/sq. ft., which enables them to fly at extremely low speeds, sometimes as slow as 4-5 mph. They are quiet in flight and can be flown in small spaces, and their low speeds allow more time for novice reactions. The inevitable crashes are usually not serious, because of the low flight speeds and low inertia of the airplanes. These airplanes provide an inherently interesting demonstration for students, as well as an enjoyable hobby for instructors.

975

Procedure: It would be best to do a little research before spending money on a particular model; the model noted in the Equipment and Materials section is simply an example, and is the one that will be demonstrated at NEW: Update 2003. Many other suitable models are available, most of them cheaper than the Butterfly. An excellent source of information is *Quiet Flyer* Magazine, published by Kiona Publishing, Inc. This monthly magazine has a great deal of technical information on models and equipment, as well as reviews of currently available planes. For the beginner, it is suggested that an airplane reviewed as for novices or beginners be purchased, as an ARF-type kit. Also, suitable radio gear must be purchased, probably from catalog sources such as the one listed above. Following the instructions and guidance from the magazine, assemble the plane strictly according to instructions, being careful to not use adhesives excessively, which can result in added weight and poor performance. The motor and speed controller are usually supplied with the kit, and should be attached as per instructions. Radio receiver and servos are next attached and rigged to move the controls, and the battery, one of the heaviest components, is mounted so that it can be easily shifted to adjust the center of gravity of the finished aircraft. After charging the battery and adjusting the center of gravity and control movements, the airplane is ready to fly, even if its owner may not yet be.

Coaching through early flight is available in several forms; one of these is to contact the closest RC airplane club and ask for an instructor to help with initial check-out and save the airplane from beginner mistakes. The other is to purchase a computer-based simulator; the one listed above is very versatile and designed to work with a PC, but needs a fast processor such as a Pentium 4 to perform best. Using this simulator and a trainer-type electric plane such as the BLT (Basic Light Trainer), one can make many mistakes with no costs in replacement or repair of airplanes. With a little persistence, one can virtually teach himself to fly the airplane.

Caution: Before attempting any type of demonstration, it would be wise to practice take-offs, flight and landings in calm-air conditions, since these airplanes are influenced strongly by wind conditions. The urge to show off, often a problem when a crowd is involved, should be resisted.

Comments: The costs of the equipment described in Equipment and Materials above may total to about $600; the sheer fun of flight is worth the price, since it may lead to an enjoyable lifelong hobby.

References: *Quiet Flyer* Magazine, Kiona Publishing, Inc., Publisher
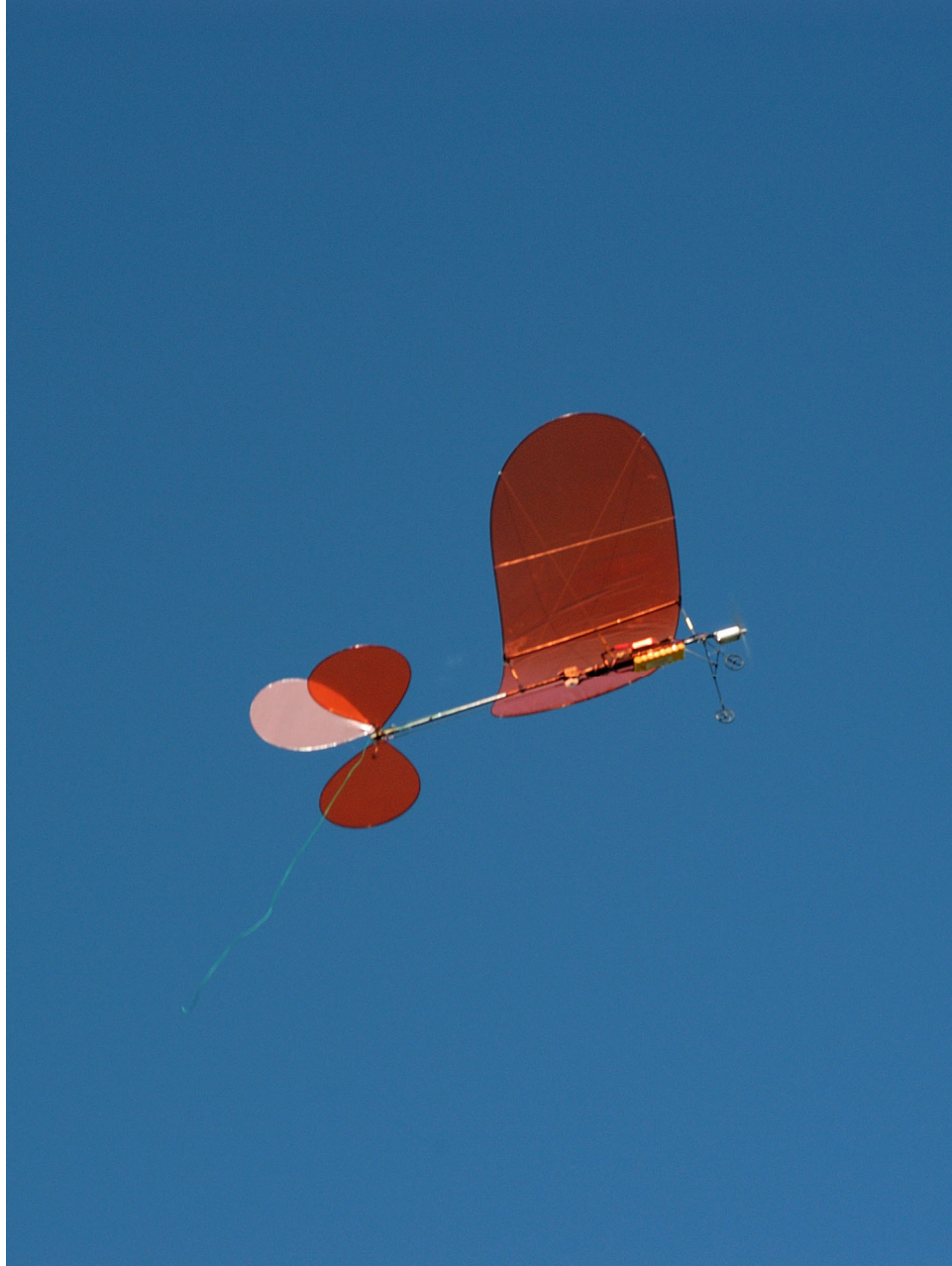
AN EXPERIMENT TO DEMONSTRATE THE THERMAL EXPANSION OF A METAL ROD
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An Experiment to Demonstrate
Thermal Stress Induced in a Metal Rod

National Educators' Workshop
October 19-22, 2003

Michael J. Kozak, School of Technology
Purdue University Programs
Richmond, Indiana

Key Words: Thermal stress

Prerequisite Knowledge: Basic knowledge of how to use a Universal Test Machine and a propane torch (plumber's torch)

Objective: To demonstrate the forces created by thermal stress induced in a metal rod

Equipment and Materials:
1. Universal Test Machine (UTM)
2. Metal rod (1 inch diameter by 12 inch long aluminum rod in this case)
3. Propane torch (plumber's torch)
4. Operator that can safely operate and/or supervise the operation of a UTM and propane torch

Introduction:

Concepts which cannot be visually demonstrated can sometimes be difficult to grasp. Thermally induced stress can be one of these hard to imagine concepts. The author has developed a simple experiment which demonstrates the loads created when a metal rod, which is constrained on both ends, is subjected to a rise in temperature.

Experimental Procedure:

A metal rod with square ends is placed in a Universal Testing Machine (UTM) and the UTM's platens are adjusted such that both platens make contact with the ends of the rod which is at room temperature. The metal rod specimen is then heated with the flame from a plumber's torch. Care must be taken to prevent injury due to contact with the flame or hot objects. Shortly after the flame is applied to the specimen, the force indicator of the UTM will begin to show an increase in load.

Comments:

Since the expansion of the rod is limited by the UTM platens, a force is registered by the UTM which is the force exerted by the rod's constrained contact with the UTM platens as it attempts to expand lengthwise. The load shown on the UTM force indicator divided by the cross sectional area of the rod will indicate the thermal stress in the rod.

The author developed this experiment for a demonstration in a Strength of Materials class. Strength of materials deals with applied loads and their internal effects on bodies [1]. Stress is defined as the internal resistance of a material due to loads [2].

The loads in our experiment are created by the constrained thermal expansion. In this way thermal stress is induced in the metal rod. Away from the ends of the rod, the applied load should be shared uniformly by the entire cross section of the member. In such cases the stress can be computed by simply dividing the total force by the cross sectional area of the member [3].

Stress is an artificial concept [4]. Thermal stress caused by constrained expansion can be difficult for the student to imagine. This experiment demonstrates the forces generated by thermal stress. Witnessing the forces generated may help the student gain an understanding of thermally induced stress.

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2. Jacobs, James A., *Engineering Materials Technology*, 4th edition, Prentice Hall, New Jersey, 2001
3. Shigley, Joseph Edward, *Mechanical Engineering Design*, McGraw Hill, San Francisco, 1977
4. Mott, Robert L., *Applied Strength of Materials*, 4th edition, Prentice Hall, New Jersey, 2002

Biography:

Since 1999, Professor Kozak has taught applied courses in Mechanical Engineering Technology, Industrial Engineering Technology and Computer Integrated Manufacturing Technology at Purdue University School of Technology in Richmond, Indiana. He has concentrated on courses in strength of materials, dynamics, heat transfer, thermodynamics, fluid power, industrial organization, statistical process control, and automated manufacturing.

He is a registered professional engineer in the state of Ohio, is a professional member of the American Society of Engineering Educators (ASEE) and is chair elect for the Illinois/Indiana section of ASEE. He was awarded a BSME from the University of Akron in 1982 and a MSME from the University of Cincinnati in 1986. From 1982 to 1984 he was a project engineer for B. F. Goodrich. From 1987 to 1999 he was a product development, quality, senior test, reliability, or procurement engineer for General Motors.

REGOLITH MATERIALS
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Sheila A. Thibeault

Regolith Materials

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Janet L. Chapman[2], J. Adam Weakley[2], and D. Ryan McGlothlin[2]

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2003 National Educators' Workshop
Hampton and Newport News, VA
October 19 - 22, 2003

Goals

- **In-Situ Resource Utilization**
  - using regolith

- **In-Space Manufacturing**
  - fabricating materials

- **Radiation Protection Methods**
  - developing habitat concepts

- **Radiation Physics**
  - measuring radiation transmission

Problem

Martian Environment

- Low-intensity energetic heavy-ion flux of Galactic Cosmic Radiation (GCR)
- Solar Particle Events (SPE)
- Neutron radiation
- Global dust storms (wind speed = 17-30 m/sec)

Mars Exploration Fact

- Earth return possible at specified times (~ every 26 months)

$\Rightarrow$ Need habitat to provide safe haven for human explorers

Martian Regolith
(Viking Lander Data)

- Average Density
  1.4 g/cm^3

- Chemical Composition
  58.2% SiO_2
  23.7% Fe_2O_3
  10.8% MgO
   7.3% CaO

Predicted Annual Dose Equivalent
Behind Martian Rocks and Martian Regolith
(cSv/yr)

Thickness g/cm^2	Basalt	Lherzolite	Clino-pyroxenite	Ortho-pyroxenite	Dunite	Martian Regolith
1	132.3	132.3	132.4	132.2	132.4	**132.3**
5	111.5	111.4	111.8	111.1	111.8	**111.5**
10	94.0	93.8	94.3	93.4	94.3	**93.9**
30	64.8	64.6	65.2	64.2	65.2	**64.8**
50	56.5	56.2	56.8	55.9	56.8	**56.5**

Predicted Biological Responses
Behind Martian Regolith and Aluminum
After 1-Year GCR Exposure

Thickness g/cm^2	C3H10T1/2 Cell Death Rate, %	C3H10T1/2 Cell Transformation Rate, x 10^{-3} %	Excess Harderian Gland Tumor Prevalence, %
Martian regolith			
1	3.92	1.74	3.50
5	3.28	1.65	3.28
10	2.74	1.54	3.02
30	1.89	1.34	2.63
50	1.65	1.29	2.56
Aluminum			
1	3.94	1.76	3.57
5	3.33	1.70	3.37
10	2.80	1.59	3.12
30	1.91	1.39	2.73
50	1.65	1.33	2.63

Predicted Biological Responses Behind Various Materials After 1-Year GCR Exposure

(a) Dose Equivalent

(b) Excess Harderian Gland Tumor Prevalence
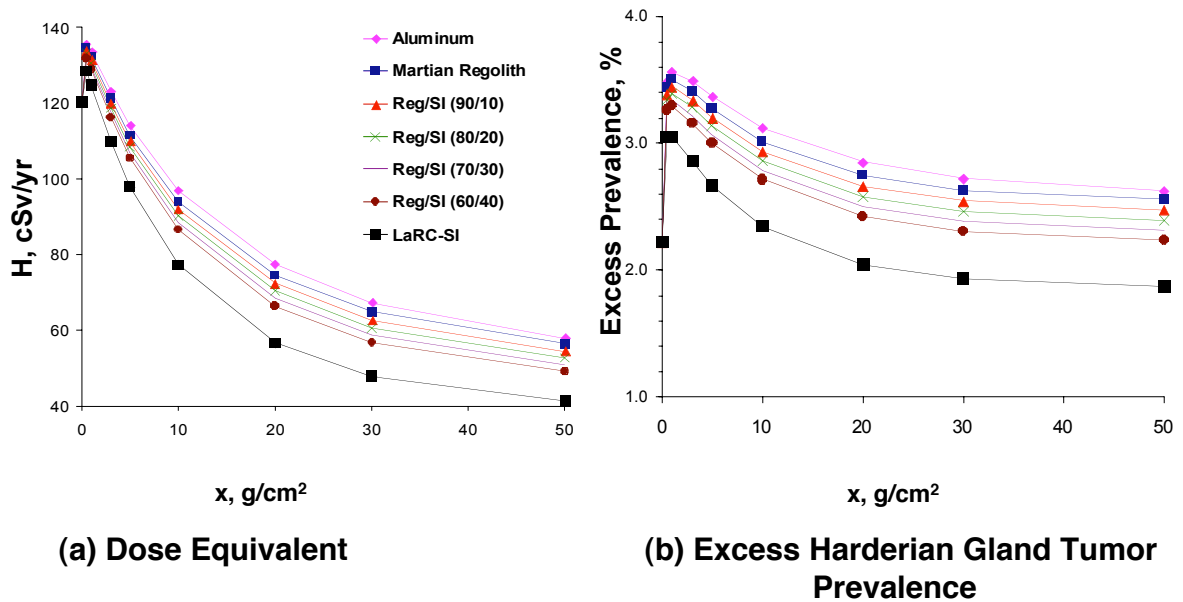
Fabrication of Shielding and Habitat Components for Ground Tests

Polymer   Regolith Powder

LaRC-SI   Regolith Simulant Powder   Mixed Powder

Mix

De-aerated at 71-77°C under Vacuum

Mold   Press or Oven   Bulk-Molded Microcomposites
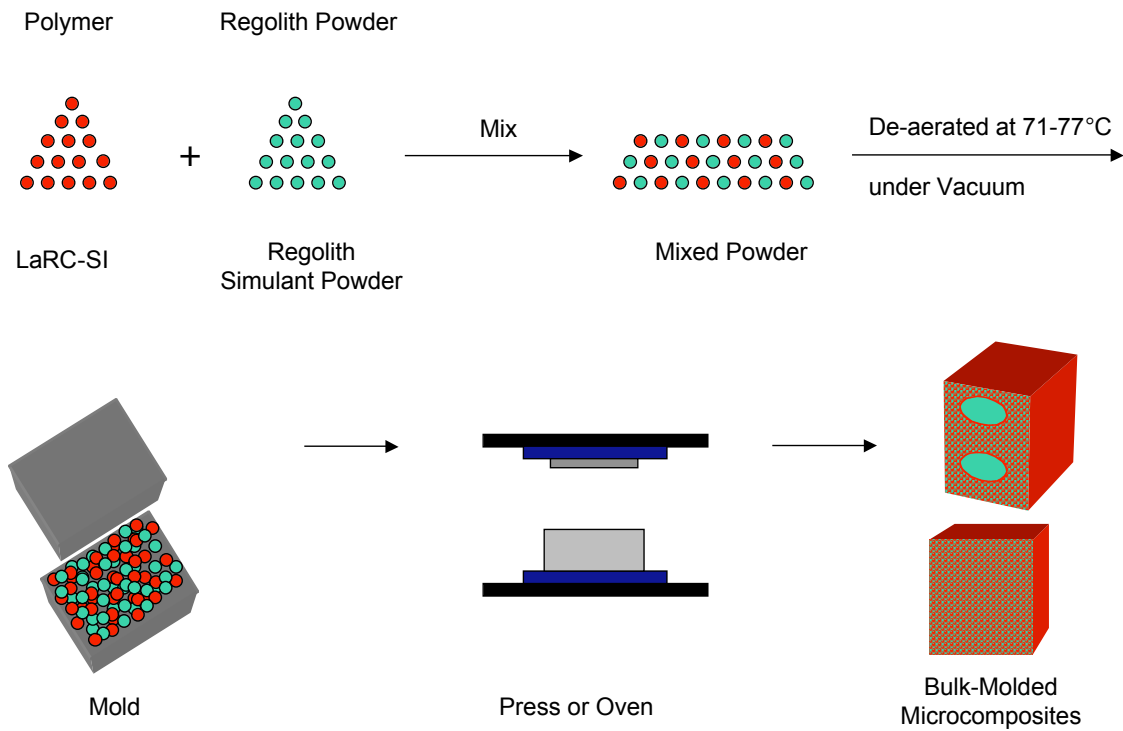
Habitat Construction/Radiation Shielding for Martian Exploration and Development

n, p⁺,.., α⁺⁺,.., C⁺⁶,.., O⁺⁸,.., Mg⁺¹²,.., Si⁺¹⁴,.., Fe⁺²⁶
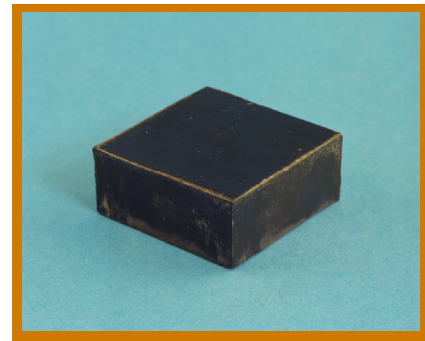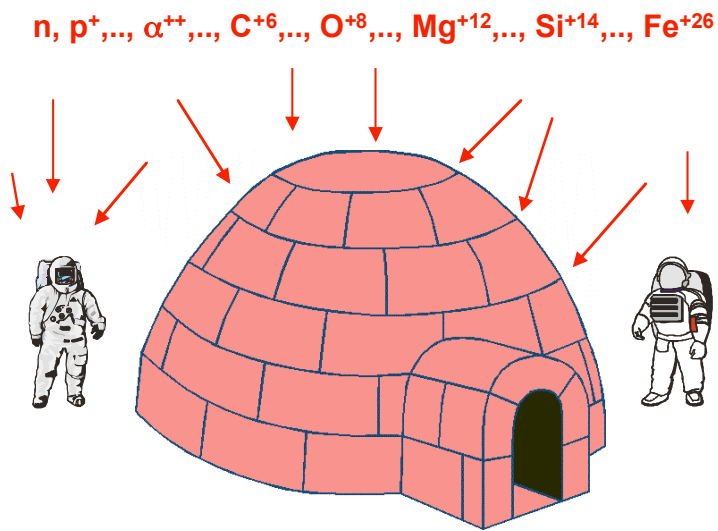
Regolith/LaRC-SI
(80%/20% by weight)
microcomposite block

Microwave Oven

Manufacturer: Panasonic
Model #: NN-S950
Oven size: 14" x 23 7/8" x 19 1/2" (h x w x d)
Cavity size: 11" x 18 1/2" x 18 1/2" (h x w x d)
Output: 1300 W at 2.45 GHz

Ceramic Mold for Microwave Processing
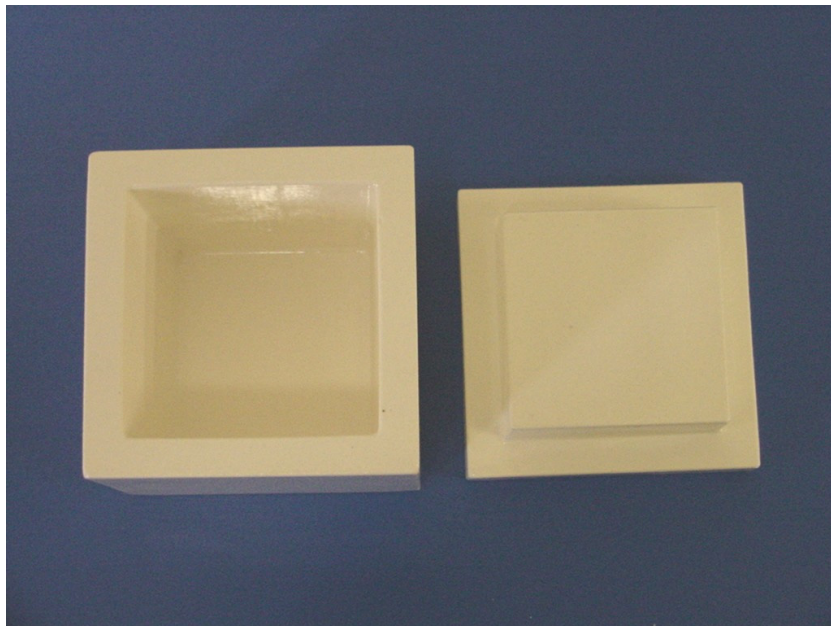
TGA Mass Loss and TMA Glass Transition Temperatures for Regolith/LaRC-SI Microcomposites
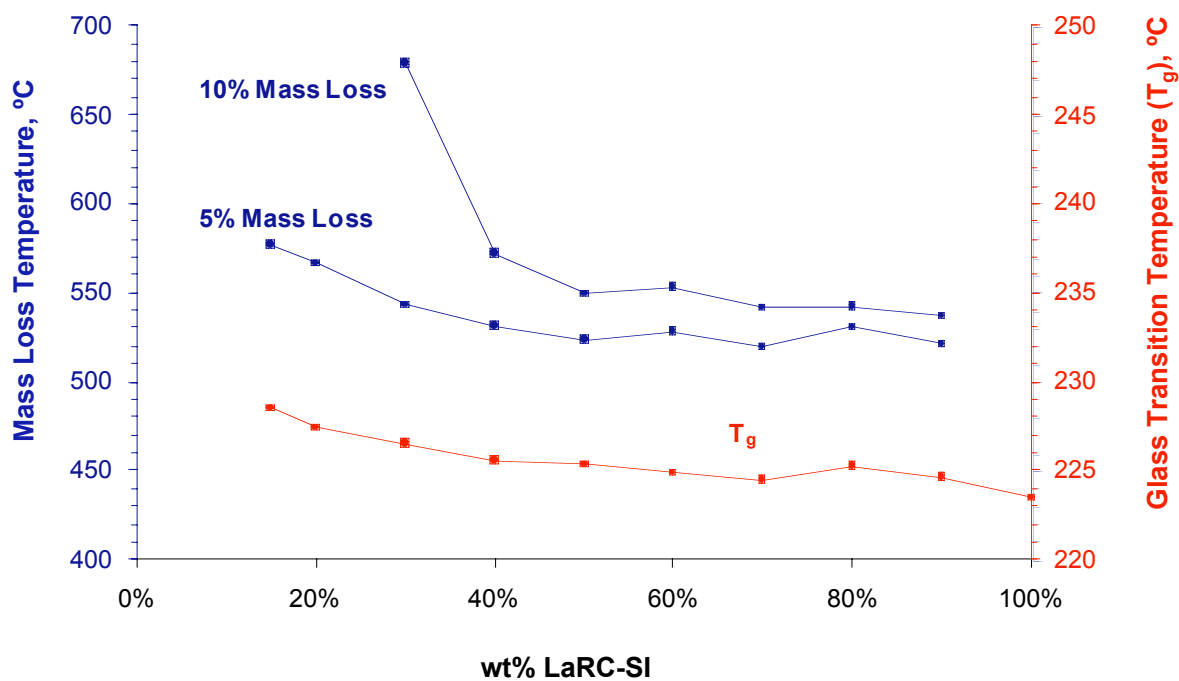
Compressive Yield Strength
for Regolith/PE Microcomposites
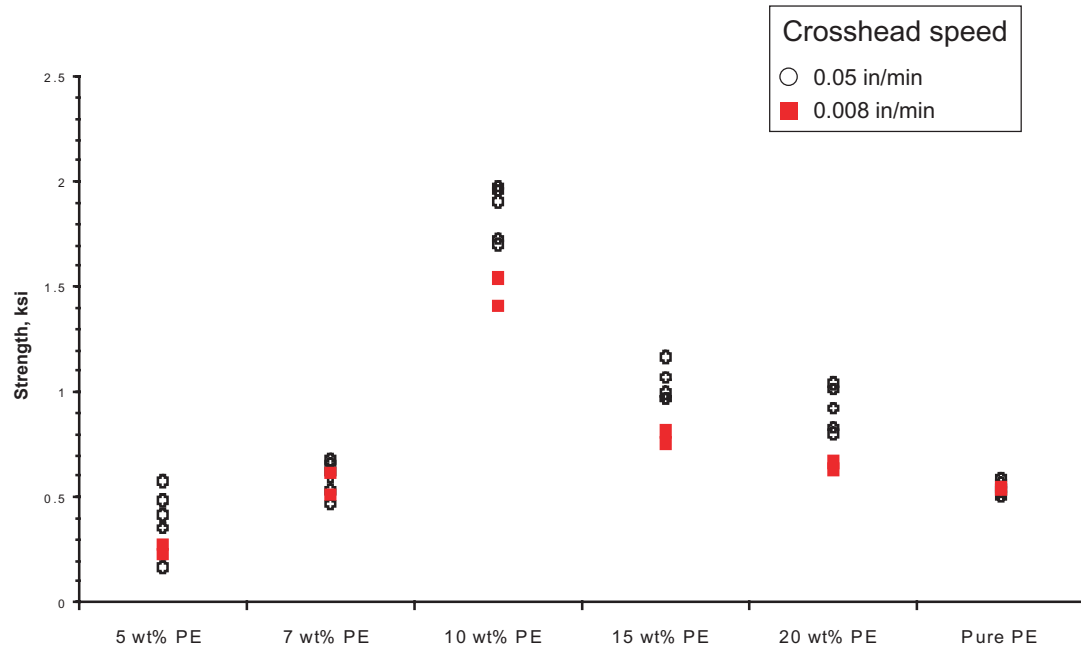
Ultimate Compressive Strength
for Regolith/PE Microcomposites
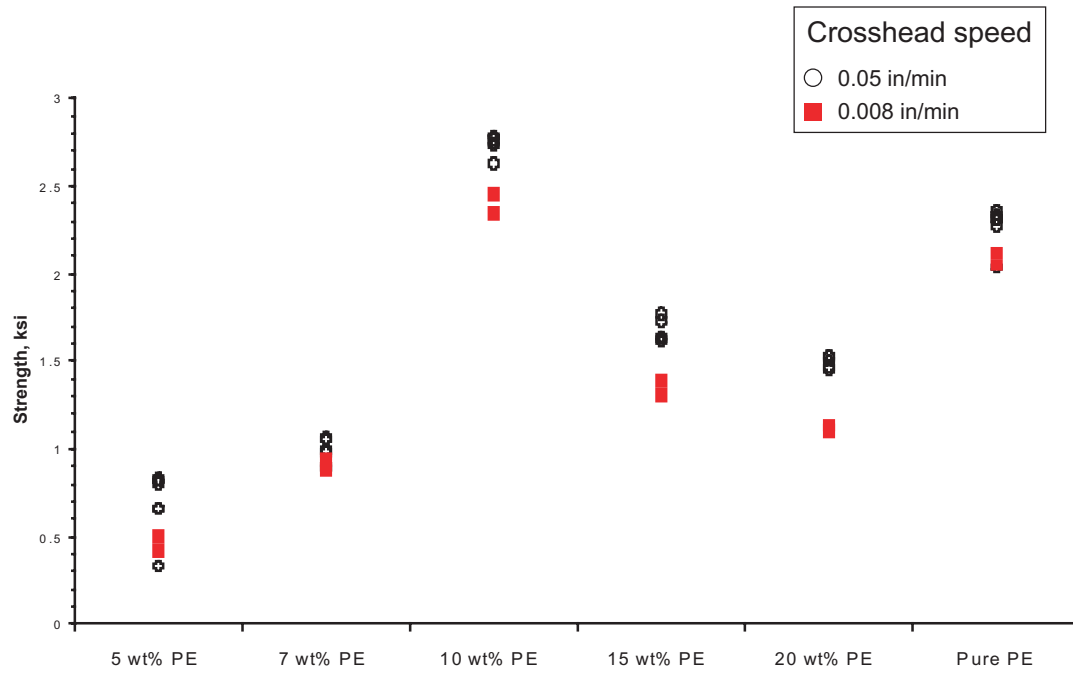
Compressive Modulus
for Regolith/PE Microcomposites
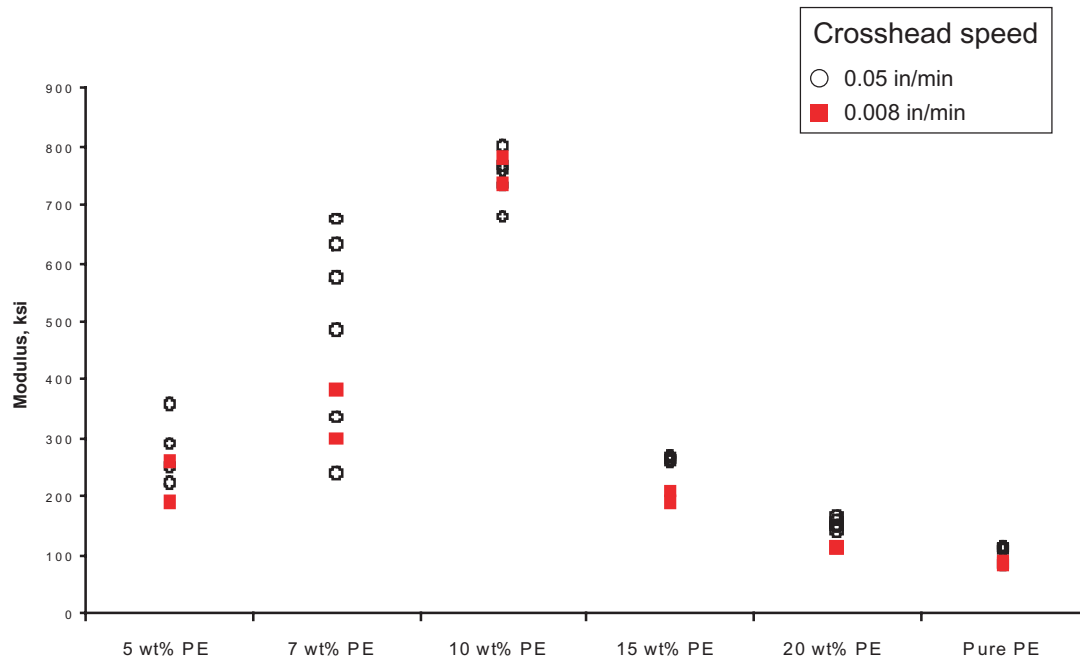
TMA Glass Transition Temperature
for Regolith/PE Microcomposites
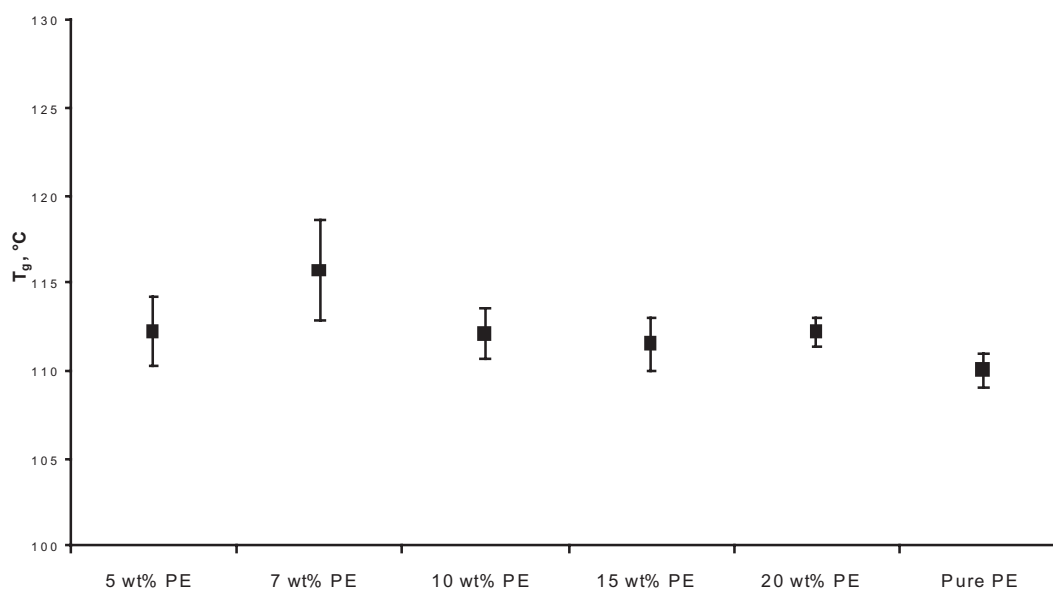
TMA Softening Temperature
for Regolith/PE Microcomposites
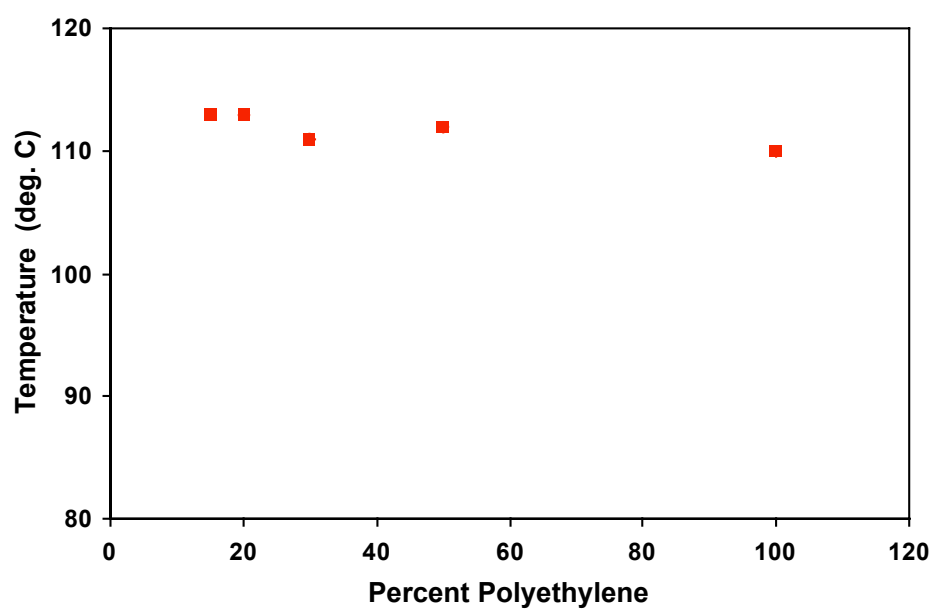
TGA 5% Mass Loss Temperature
for Regolith/PE Microcomposites
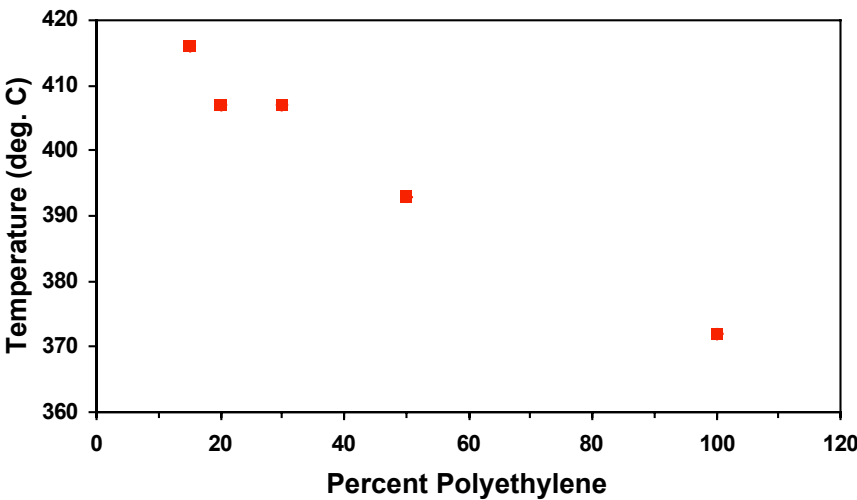
BNL-AGS/NASA Shield Test Facility
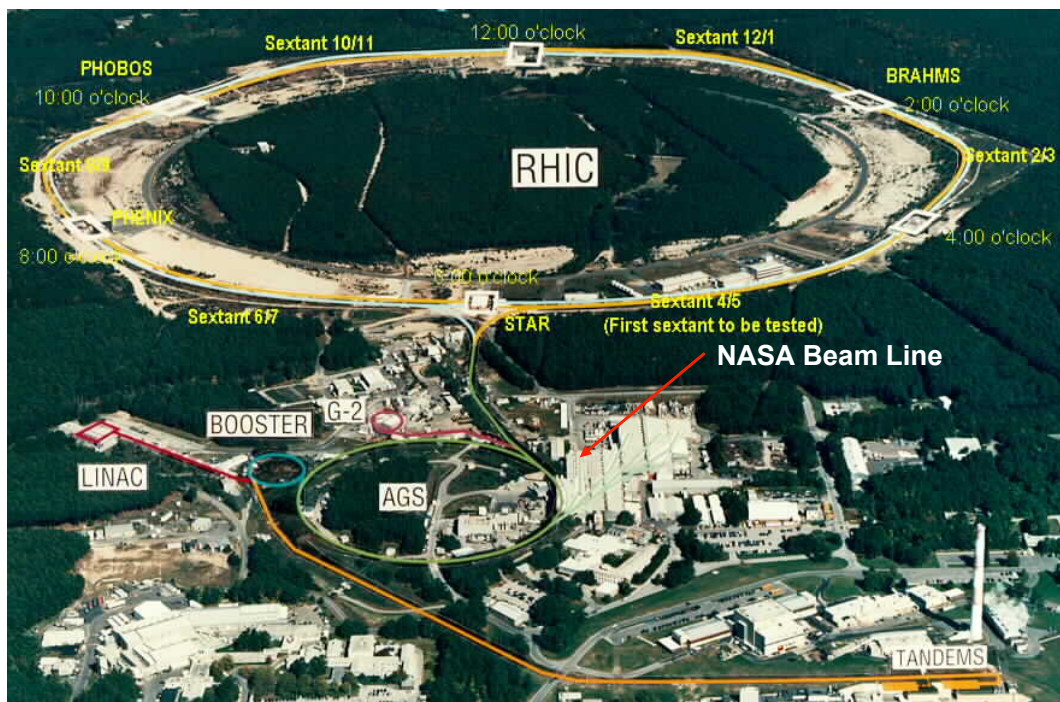
Experimental Radiation Shielding Effectiveness of Various Materials for 1.06 GeV Fe Ions
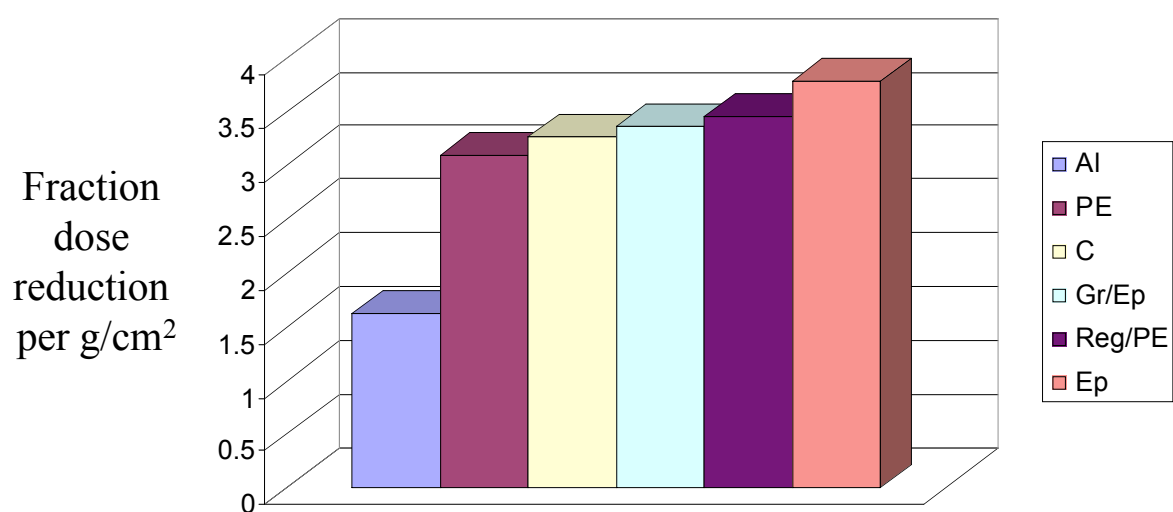
Experimental Setup of 88" Cyclotron at LBNL
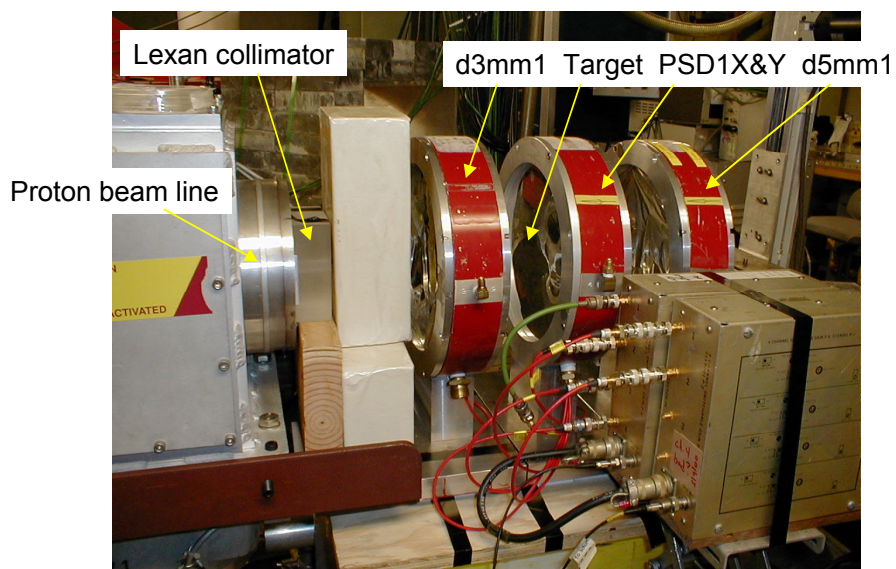
- Nearly Monoenergetic Proton Beam (34.5 ± 0.266 MeV)
- E-Spectrum without Target (23.68 ± 0.46 MeV)
- Statistics (on the order of 1-2 Million Events)

Transmitted Differential Proton Energy Spectrum
for 55-MeV Proton Beam
(2.01 g/cm^2 thick targets)

Regolith/LaRC-SI 60/40 wt %   Regolith/LaRC-SI 80/20 wt %

ϕ (E), protons/MeV

E, M e V

1006
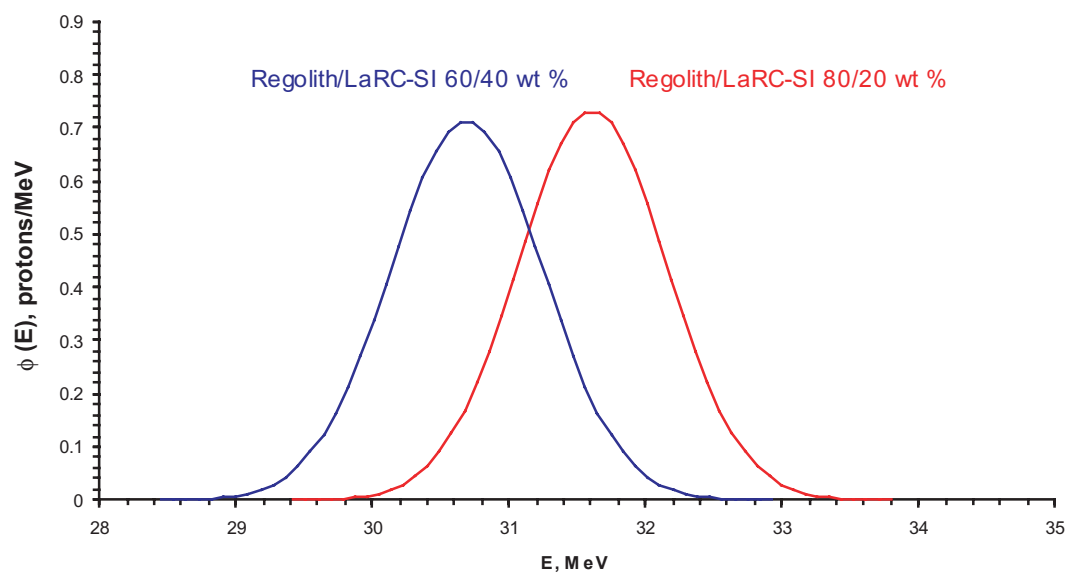
SEU on Motorola MCM6246-5V SRAM
from 55-MeV Proton Beam
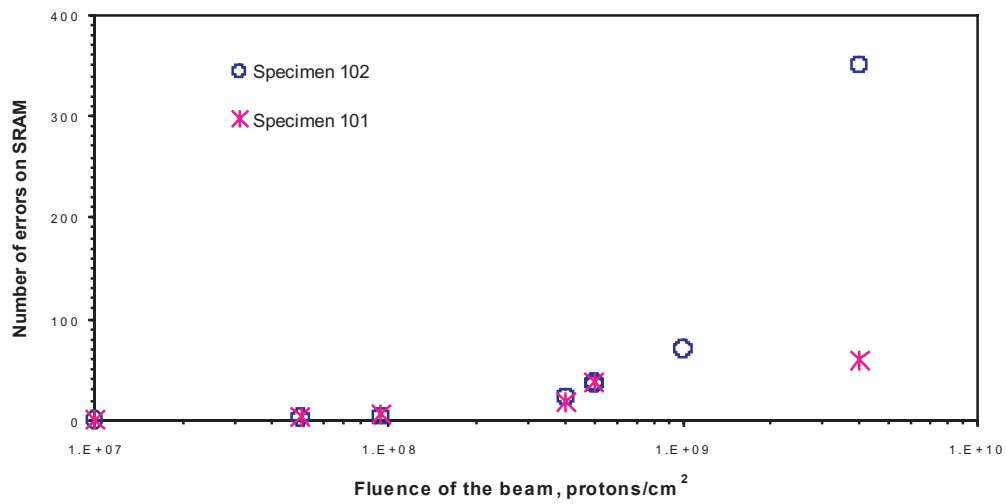
Specimen 102: 80% regolith/20% LaRC-SI
Specimen 101: 60% regolith/40% LaRC-SI

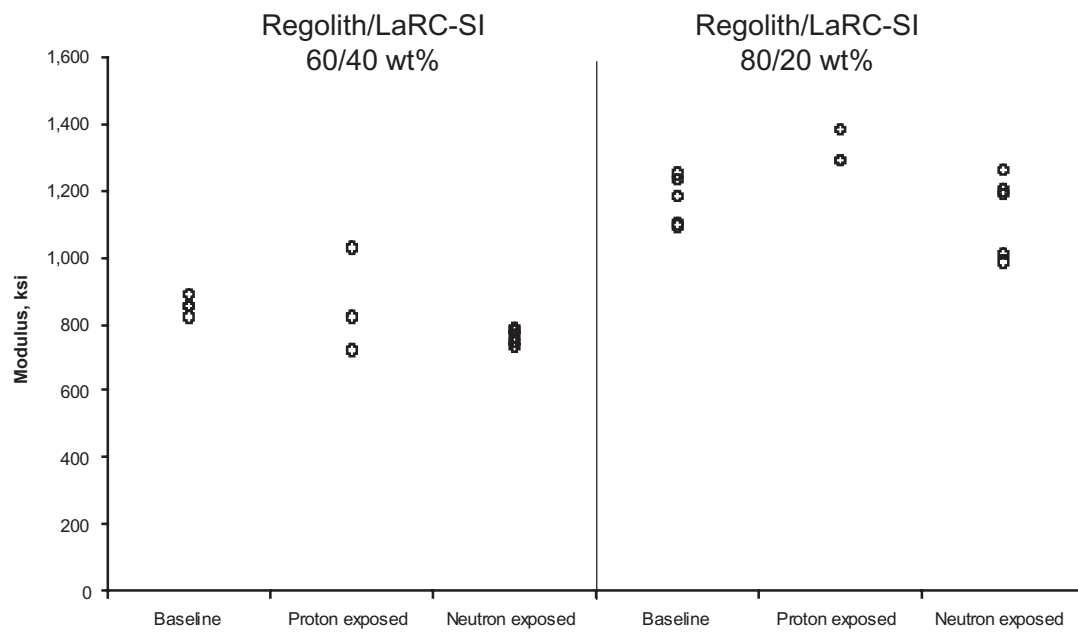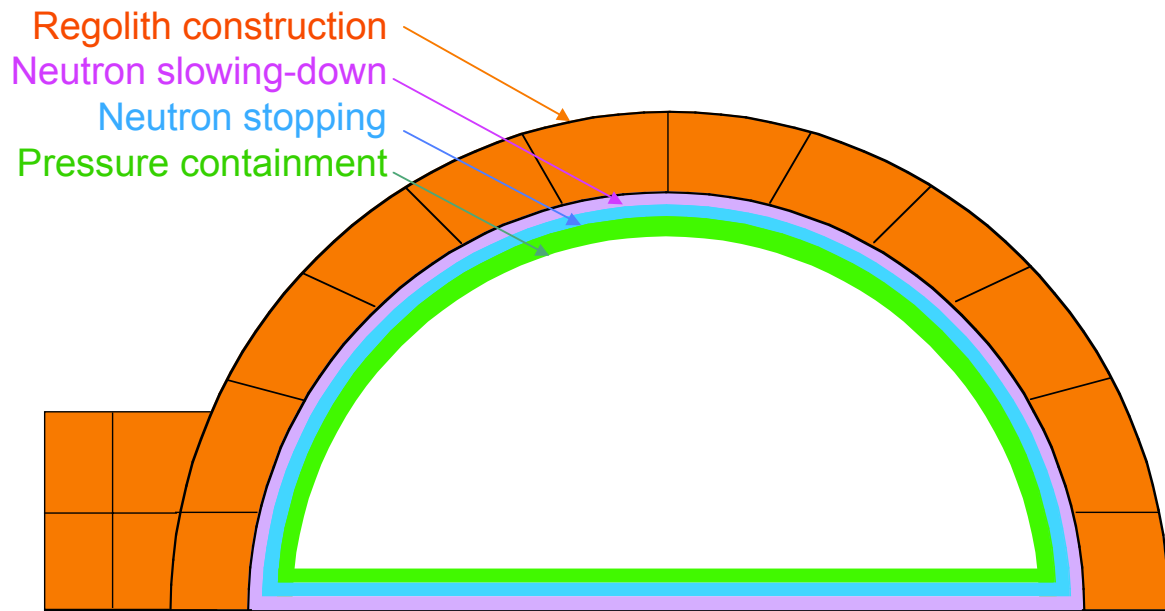# Langley Fast Neutron Shield Test Facility
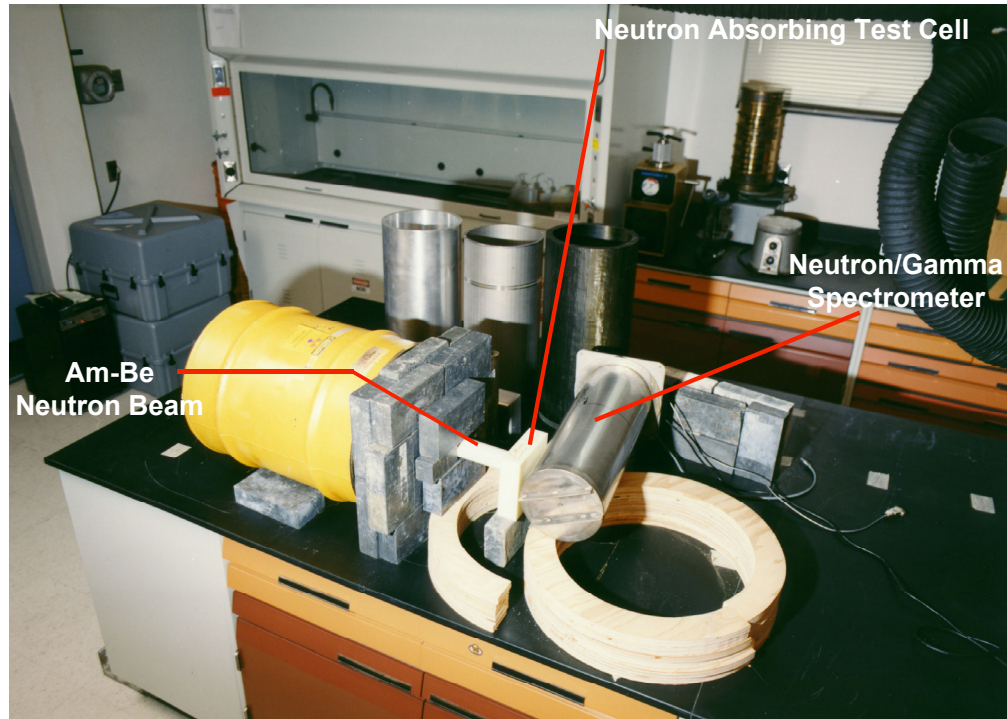
Ultimate Compressive Strength
for Regolith/LaRC-SI Microcomposites

Compressive Modulus
for Regolith/LaRC-SI Microcomposites
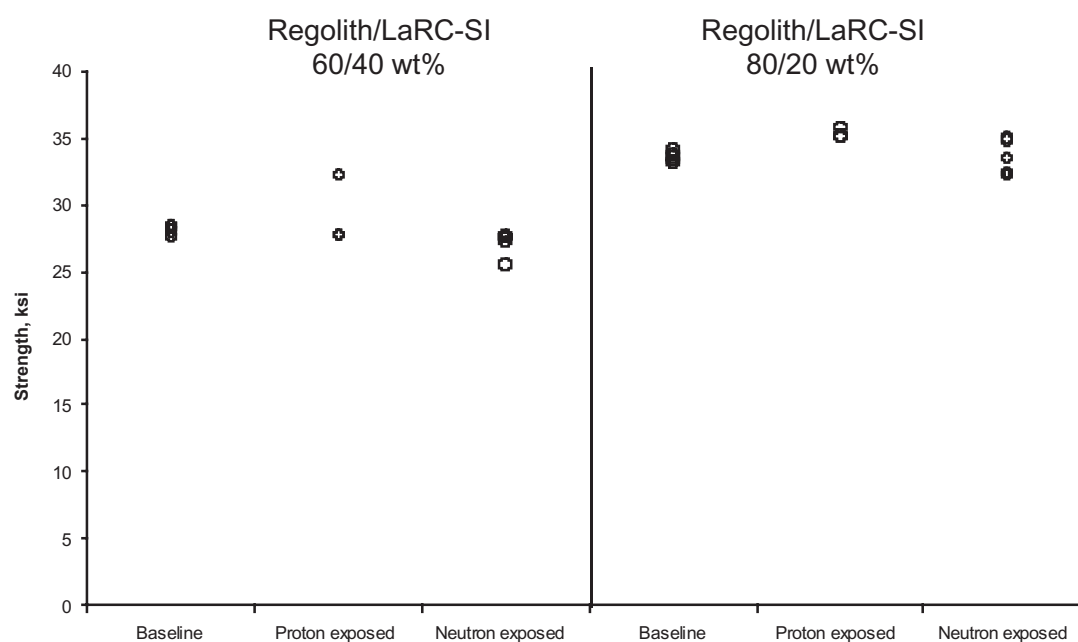
Regolith/LaRC-SI 60/40 wt%

Regolith/LaRC-SI 80/20 wt%

Multilayered Habitat Concept

Regolith construction

Neutron slowing-down

Neutron stopping

Pressure containment

INTEGRATING MATERIAL TECHNOLOGY AND INDUCTION MOTOR PRINCIPLES

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Integrating Material Technology
And
Induction Motor Principles

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Key Words: Conductors, insulators, enamel, magnetism, electromagnet, motor
principles.

Prerequisite Knowledge: Basic knowledge of electricity and magnetism.

Objective: To understand basic electric motor principles and the materials needed to
convert electricity and magnetism into motion.

Equipment:

One 'D' cell alkaline battery
One wide rubber band
Two three inch lengths of heavy gauge copper wire
One rectangular ceramic magnet
Heavy gauge magnet wire
Fine sandpaper
Needle-nosed pliers

Introduction:

This is a tremendous activity, originally developed by Beakman's World, which I
have perfected over the past ten years of teaching motor principles at the
university level. Standard *Radio Shack* materials can be used. Heavy gauge
copper wire is used to fabricate the coil cradle, and the cradle is attached to a
standard "D" size battery with elastic bands. After winding the motor coil, we
remove insulation from two locations with sandpaper and assemble the device.

When the un-insulted parts of the coil make contact with the cradle, current flows
through the coil, making it into an electromagnet. Since magnets attract, the coil
attempts to align itself with the magnet. However, when the coil turns to face the
magnet, contact is broken, and the magnetic field collapses. Inertia causes the
coil to continue around until contact is reestablished and the process repeats itself.
In other words, the motor revolves continuously.

Procedure:

1. Start about 3 inches from the end of the magnet wire and wrap it seven times around the battery. Remove the battery and cut the wire, leaving a three-inch tail opposite the original starting point. Wrap the two tails around the coil so that the coil is held together and the two tails extend perpendicular to the coil.

2. On one tail, use fine sandpaper to completely remove the insulation from the wire. On the other tail, lay the coil down flat and lightly sand off the insulation from the top half of the wire <u>only</u>.

3. Using needle-nosed pliers, bend the two heavy copper wires. Form a cradle on one end that will hold the coil, and form a loop on the other end that will contact the battery.

4. Use a rubber band to hold the loop ends to the terminals of the "D" cell battery.

5. Stick the ceramic magnet on the side of the battery between the attached copper wires.

6. Place the coil in the cradle formed by the ends of the paper clips. You may have to give it a gentle push to get it started, but it should begin to spin rapidly.

Comments:

Balance is important, so be sure to center the two tails on either side of the coil.

If it doesn't spin, check to make sure that all of the insulation has been removed from the wire ends.

If it spins erratically, make sure that the tails on the coil are centered on the sides of the coil.
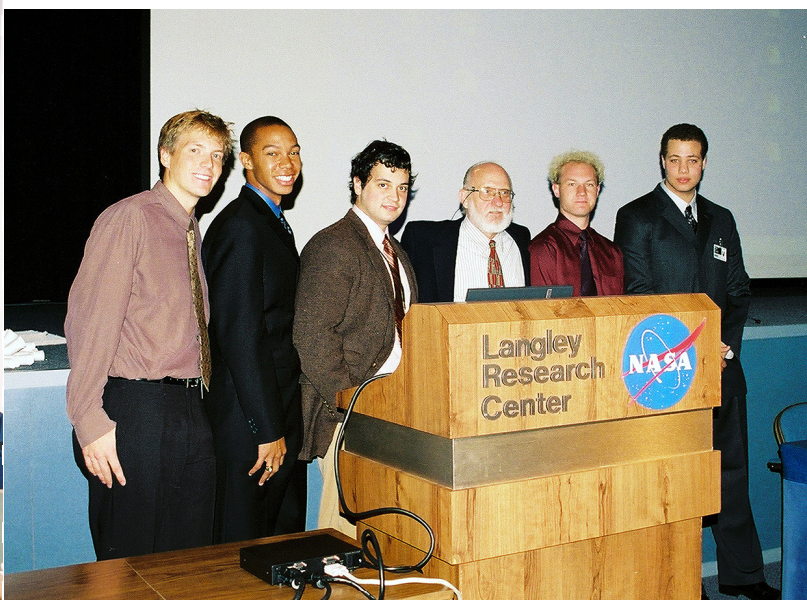
References:

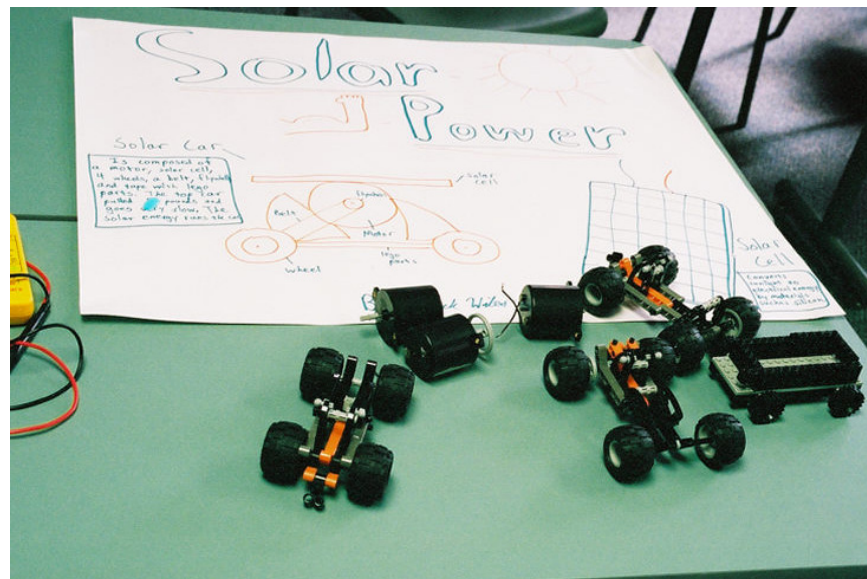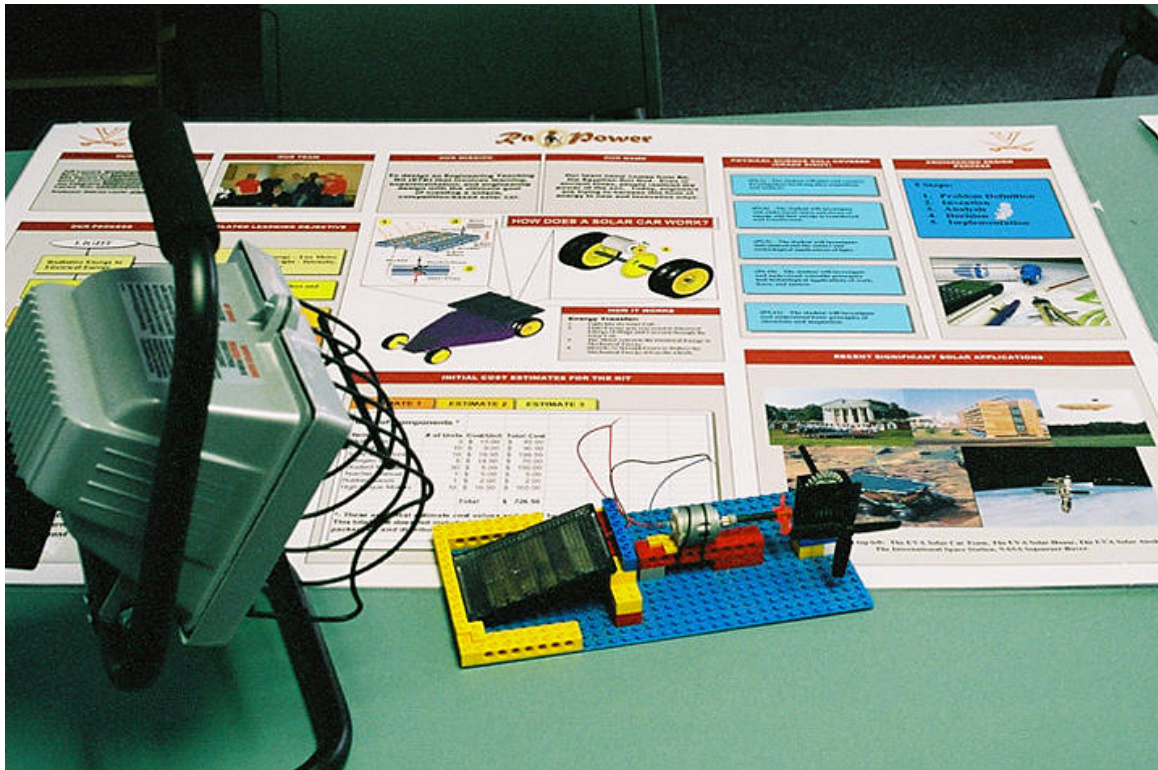Beakman's Electric Motor
Beakman's World Show

Bibliography:

Dr. JOHN ALLEN MARSHALL taught senior high school prior to receiving his Ph.D. from Texas A&M University. He has nineteen years of university teaching experience, and is currently the Coordinator of the Industrial Power and Control curriculum and laboratories as well as the Internship Coordinator for the University of Southern Maine's Department of Technology.

NATIONAL INSTITUTE OF AEROSPACE PRE-COLLEGE TEACHERS' PROGRAM AND OTHER WEDNESDAY ACTIVITIES
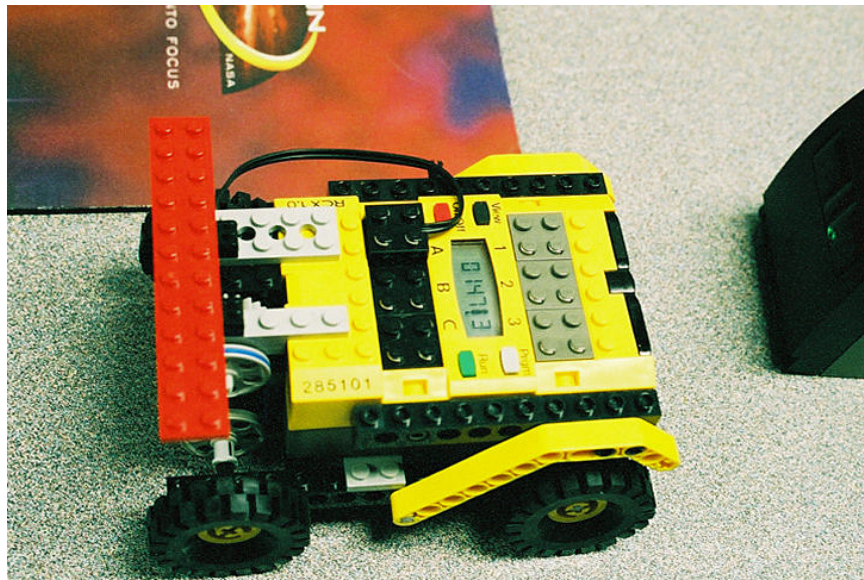
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The 18th Annual National Educators' Workshop [NEW:Update 2003] was a part of NASA Langley's celebration of the Centennial of Controlled, Powered Flight by Orville and Wilbur Wright on December 17, 1903. The conference proceedings from NEW:Update 2003 reflect the Flight 100 theme by first providing a historic perspective on the remarkable accomplishments of the Wright Brothers. The historical perspective set the stag for insights into aeronautics and aerospace structures and materials now and into the future. The NEW:Update 2003 proceedings provide valuable resources to educators and students in the form of visuals, experiments and demonstrations for classes/labs at levels ranging from precollege through college education.

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